JOURNAL OF AGRICULTURAL RESEARCH

VOL. XIII WASHINGTON, D. C., JUNE 10, 1918 NO. 11

PHYSICAL PROPERTIES GOVERNING THE EFFICACY OF CONTACT INSECTICIDES[1]

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INTRODUCTION

It was considered by Shafer (*16*)[2] that the vapor of contact insecticides such as kerosene, gasoline, creolin, and pyrethrum were responsible for the death of insects to which these materials were applied. It was therefore assumed as a working basis that the volatility of organic compounds, which has previously been shown to be an index of the toxicity of their vapors to insects (*11*, *12*), would also be an index of the toxicity of these compounds when used as contact sprays. In working with insect eggs (*14*), however, it was found that materials not sufficiently volatile to kill insects or their eggs by their vapor within a reasonable length of time, were among the most effective materials when applied to the eggs as liquids. Further studies in which different fractions of kerosene were used (*13*) revealed the fact that the least volatile fractions were the most effective as contact insecticides, while they failed to kill insects which were exposed only to their vapor.

With these results in mind it was considered advisable to determine the physical properties governing the entrance into the insect of a contact insecticide, and wherein this differs from the penetration of the vapor.

WETTING AND SPREADING OF THE INSECTICIDE

It is common observation that when some contact insecticides strike an insect they form into round droplets which roll off the body, while others spread out, forming a film over the insect. This phenomenon of the spreading out of the insecticide over the body has been often termed "wetting" or "spreading" and is often confused with the wetting and spreading of the insecticide over the surface of the leaves sprayed, the terms "wetting" and "spreading" being used synonymously. Vermorel and Dantony (*18*, *19*, *20*), Lefroy (*5*), and more recently Cooper and

[1] Published, with the approval of the Director, as Paper 112 of the Journal Series of the Minnesota Agricultural Experiment Station.

[2] Reference is made by number (italic) to "Literature cited." p. 537-538.

Nuttall (*2*) have studied the physical principles governing the wetting and spreading of contact insecticides and have endeavored to devise means by which these important properties may be easily measured. In all of these papers the authors have failed to distinguish between wetting and spreading. In this paper a distinction will be drawn between these two terms. If a liquid is placed upon a solid, and there is a specific attraction between the two, they will come into actual contact. The slight chemical affinity exhibited between the two substances is what is denoted as wetting, or adhesion between the liquid and the solid. For example, if a drop of mercury is placed upon glass, there is no specific attraction between the two, owing to the film of moisture and air on the surface of the glass (*3*, *p. 176*). Hence, the mercury is said not to wet the glass, and there is no adhesion between the two. By boiling the mercury in a glass tube and thus expelling the moisture and air between the mercury and the glass, it is found that there is an actual wetting of the glass by the mercury, as is indicated by adhesion.

If a liquid is brought into contact with a solid and wetting takes place, the spreading of the drop into a thin film may or may not occur. The law governing spreading has been carefully explained by Cooper and Nuttall (*2*). They find that if the surface tension of the substance upon which the spray is placed is greater than the surface tension of the spray plus the surface tension at their interface (interfacial tension), the liquid will spread. Otherwise there will be no spreading. Bigelow and Hunter (*1*) have given a very much simpler explanation of the whole matter. They consider (*p. 377–387*) that if a liquid is in contact with a solid—that is, actually wetting the solid—two forces are at work:

> First, the cohesion between the like particles of the liquid which, in the surface layer is denoted by the phrase "surface tension," and second, the adhesion between the liquid and the walls [solid].

Thus, if adhesion to the solid is stronger than the cohesion of the liquid, the liquid will spread over the solid. The same law applies when two liquids are in contact. The following experiment will serve as an example. If a filter paper is soaked in water and spread out flat on a glass plate, a drop of kerosene on this wet paper will quickly spread into a thin film. In this case the adhesion between the water and the kerosene is greater than the cohesion of the kerosene. On the other hand, if the filter paper is soaked in kerosene and a drop of water placed upon it, the water does not spread out into a thin layer. In this case the cohesion of the water is greater than the adhesion between the water and the kerosene, which is the same in both experiments. Thus, it is clear that there must be wetting before there can be spreading, but it does not necessarily follow that when there is wetting there must be spreading, for otherwise the water would have spread over the kerosene.

One other factor has a considerable influence on the spreading of an insecticide—namely, viscosity. Viscosity may be defined as "the inter-

nal friction of a liquid." Although the viscosity does not influence the ultimate extent to which a liquid may spread, it does have a very decided influence on the rate of spread. It is possible that a liquid may be so viscous that the rate of spread may be reduced to such an extent as to make it valueless as an insecticide.

From the foregoing statements it is apparent that when a spray strikes an insect, if there is a chemical affinity between the insecticide and the chitin which forms the outer covering of the insect, wetting will take place and the insecticide will adhere. If the cohesion of the spray is less than the adhesion between the chitin and the spray, then the liquid will spread over the body of the insect. The rate at which this spreading will take place is governed by the viscosity of the liquid. If the cohesion is greater than adhesion, the spray will form into droplets which tend to roll off. The same result is obtained when the spray does not wet the insect. It is apparent therefore that in a contact insecticide it is important not only that the liquid should wet the chitin, but also that the adhesion of the liquid to the chitin should be greater than the cohesion of the liquid.

RELATION BETWEEN SPREADING AND CAPILLARITY

The rise of a liquid in a capillary tube is governed by the same laws as the spreading of a liquid over the surface of a solid. First, unless the liquid has a specific attraction for the material of which the tube is composed (wetting), there can be no capillary rise. Second, unless the adhesion between the liquid and the walls of the tube is greater than the cohesion of the liquid, there can be no capillary rise. This is well shown by Bigelow and Hunter's (*1*) studies of the rise of water in capillary tubes of different materials. In their experiments the cohesion of water remained the same, but owing to different degrees of adhesion between the water and the walls of the capillary tubes, variations were noted in the height to which the liquid rose in tubes of different materials. It is evident, therefore, that since the tracheæ are lined with chitin, similar to the covering of the body wall, insecticides which will spread over the body will also penetrate the tracheæ by capillarity, while those insecticides which do not spread over the insect, even though they may come in contact with a spiracle, will not be able to penetrate the tracheæ.

Contact insecticides may therefore be divided roughly into two groups: First, those which wet the insect and, owing to greater adhesion than cohesion, are able to spread over the surface of the body and pass up the tracheæ by capillarity. Second, those which wet the insect, but which, owing to a higher cohesion than adhesion, are able neither to spread over the surface nor to gain entrance into the tracheæ by capillarity.

PENETRATION OF LIQUIDS INTO THE TRACHEÆ

From the results of Cooper and Nuttall (*2*) it would appear necessary to make a determination of the surface tension of the insecticide, the surface tension of the chitin, and the surface tension at the interface of the chitin and the insecticide before it could be determined whether or not the liquid would spread over the body and penetrate the tracheæ. From the results of Bigelow and Hunter (*1*), however, the capillary rise in a tube really determines whether the adhesion between the liquid and the solid is greater than the cohesion of the liquid, or, in other words, is a

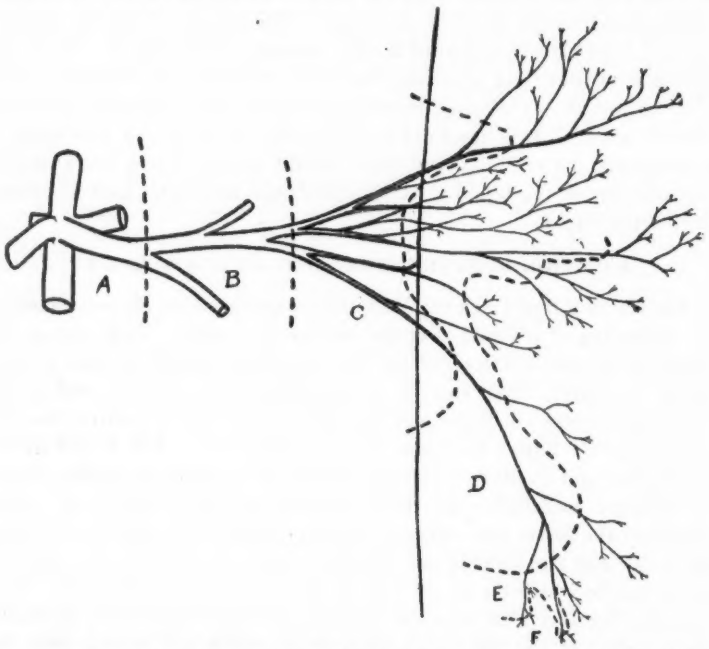

FIG. 1.—Sketch of a trachea of the cockroach divided into sections A, B, C, etc., to indicate the distance the various oils penetrated. See Table I.

means of determining whether the surface tension of the solid is greater than the surface tension at the interface between the solid and the liquid plus the surface tension of the liquid. By placing an insect in the insecticide to be studied for a short period and then dissecting it, it is possible to determine whether or not the insecticide has penetrated the tracheæ, and approximately how far. These results give an index of the spreading ability of the different materials.

The cockroach (*Blatella germanica* L.) was used in the following experiments for determining the penetration of insecticides into the tracheæ. The results were checked over with certain of the compounds using the wax-moth larvæ (*Galleria mellonella*), the larvæ of the Indian meal moth

(*Plodia interpunctella* Hbn.), and certain aphids. The methods of procedure were as follows: The liquid to be tested was stained with Sudan III or trypan-blue, both of which are colloids, and therefore will not pass through a semipermeable membrane. The cockroach was placed into the liquid and allowed to remain for from 15 minutes to 2 hours, depending upon the viscosity of the liquid. After a sufficient time had been allowed for the liquid to penetrate, the cockroach was removed and opened on the ventral side. The tracheæ which were penetrated by the material stood out either red or blue, and it was very easy to determine the extent of the penetration.

Table I gives a list of the materials used and shows their power of penetration. The letters represent the distance the material penetrated into the tracheæ as illustrated in figure 1.

TABLE I.—*Materials used in experimental work, showing their power of penetration*

Name.	Penetration.[a]	Name.	Penetration.[a]
Distilled water	O	Lubricating oil 6	D to E
Saponin solution (1:500)	O	Cod-liver oil	D to E
Gelatin solution (1:1,000)	O	Oil of pine needles	E
Nicotine solution	O	Oil of juniper	E
Glycerin	O	Rape-seed oil	E
Lime-sulphur solution	O	Raw linseed oil	E
Alcohol (50 per cent)	O	Lubricating oil 1	E
Milk	O	Peanut oil	E
Ivory soap (1:150 at 24° C.)	A	Knochen oil	E
Croton oil	A	Lubricating oil 2	E
Lubricating oil 11	A	Wood creosote	E
Nicotine	A	Olive oil	E
Acetic acid	A	Acetone	E
Furfurol	A to B	Ether	E
Soft soap (1:150 at 24° C.)	B	Gasoline	E
Yellow soap (1:150 at 24° C.)	B	Benzyl alcohol	E
Ivory soap (1:150 at 36° C.)	B	Chlorbenzene	E
Oil of tar	B	Nitroxylene	E
Cassia oil	B	Oil of verbena	E to F
Clove oil	B	Oil of camphor	E to F
Lubricating oil 7	B	Oil of lemon	E to F
Boiled linseed oil	B	Oil of citronella	E to F
Lard oil	B	Oil of lavender	F
Castor oil	B	Oil of sassafras	F
Absolute alcohol	B	Oil of eucalyptus	F
Trimethylene cyanid	B	Oil of bergamot	F
Nitrobenzene	B	Oil of hemlock	F
Methyl salicylate	B	Oil of tansy	F
Quinolin	B to C	Oil of mustard	F
Oleoresin of black pepper	C	Red oil	F
Castile soap (1:150 at 24° C.)	C	Coal-tar creosote	F
Cedar oil	C	Cottonseed oil	F
Fish oil	C	Oil of turpentine	F
Petrolatum	C	Carbon bisulphid	F
Amyl alcohol	C	Xylene	F
Oil of bitter almonds	C to D	Chloroform	F
Whale oil	D	Chlorpicrin	F
Eugenol	D	Petroleum ether	F
Lubricating oil 5	D to E		

[a] See figure 1 for explanation of letters.

It will be noticed that aqueous solutions other than soap solutions do not penetrate the tracheæ. It was interesting to note that both nicotine and absolute alcohol are able to penetrate the tracheæ, but when greatly diluted with water they are no longer able to enter. Those substances which in an aqueous solution exhibit surface viscosity, such as saponin, gelatin, and casein, do not penetrate the tracheæ. Those materials have frequently been employed in preparing emulsions (*4*, *20*, *21*). It is apparent from the table as a whole that compounds which are soluble in ether or are capable of dissolving fats or oils are able to spread over the body of the cockroach and penetrate the tracheæ. Such substances as acetic acid, furfurol, and nicotine are not particularly good fat solvents, and it may be noted that they did not penetrate any great distance into the tracheæ. Compounds with a high viscosity, such as lubricating oil, failed to penetrate far into the tracheæ; but if these viscid substances had been given a longer time they would undoubtedly have penetrated much farther. Some soap solutions, such as ivory, gel at room temperatures in dilutions ordinarily used in spraying (1:150 or 200), and are therefore unable to penetrate to any great extent. The penetration of such a soap solution is increased when its cohesion is reduced by raising the temperature of the solution. Soft soap and yellow soap were liquid at the same dilution and penetrated better than Ivory soap, while Castile soap, manufactured from the liquid oleic acid, penetrates very well.

According to Morgulis (*15*) the exact chemical composition of chitin is still questionable. From our results its composition must be such that it is easily wetted by oils and oil solvents, or perhaps the surface of the chitin itself contains or is coated with an oily or a fatty substance. These results can not be applied to all insects, as some have special coverings of wax over the chitin. The spreading of sprays on such insects can, however, be determined by our methods with little trouble.

RELATION OF VISCOSITY AND VOLATILITY TO THE PENETRATION OF THE TRACHEÆ

The foregoing results have been primarily concerned with the pure materials. Inasmuch as the pure materials are seldom applied in actual practice, the question arises as to what takes place, when an emulsion of an oil is used in spraying. By placing drops of the emulsion on the wings, and also on the bodies of cockroaches, it was found that the oil droplets were completely surrounded by the emulsifier and did not come in contact with the body of the insect. The ability of such a spray to adhere to the insect, to spread over the body, and to penetrate the tracheæ depends, therefore, on the character of the emulsifier and not on the emulsified oil. Three distinct types of emulsions were noted: First, emulsions made with gelatin or saponin formed a round drop and tended to roll off the insect, just as did pure aqueous solutions of these

materials. Second, emulsions made with Castile or soft soap adhered to the insects and spread over the body, penetrated the tracheæ, carrying the emulsified oil with them. Third, emulsions made with using Ivory soap adhered to the body of the insect; but, owing to the high cohesion of the liquid, spread very slowly. In the third case it was noticed that in a comparatively short time, depending upon the temperature and humidity of the surrounding atmosphere, the water evaporated and the emulsion broke down, after which the oil spread over the surface of the body, penetrating the tracheæ. The length of time required for the breaking of the emulsion was from 5 to 30 minutes. If the oil was rather volatile, it would evaporate before it succeeded in penetrating the tracheæ. By spraying a number of insects it was determined that oils more volatile than xylene were too volatile to succeed in penetrating the tracheæ in large enough quantities to result in the death of the insect. On the other hand, the oil may be so viscous that, even after the breaking of the emulsion, it is unable to spread over the body and enter the tracheæ in a reasonable length of time. The viscosity of a number of oils was determined in terms of water by measuring the length of time required for 5 c. c. of the liquid to flow through a glass tube of small diameter arranged in the form of a stalagmometer. The results of these are shown in Table II.

By placing a small drop of oil on the wing of a cochroach and watching it under the miscroscope it was possible to divide the oils into four classes: (1) Those spreading rapidly, (2) those spreading slowly, (3) those spreading very slowly, and (4) those spreading so slowly as to preclude any possibility of their reaching the spiracles in a reasonable length of time.

The oils in Table II are divided into these four groups. It is apparent that oils with a viscosity as high or higher than castor oil are so viscous that their value as contact insecticides is questionable.

TABLE II.—*Viscosity of various oils*

Material.	Time.	Viscosity, in terms of water.	Spreading ability.
	Seconds.		
Water (distilled)	3.3	1.00	
Kerosene (b. p. 140°–187°)	3.6	1.10	Rapid spreader.
Kerosene, unfractionated	4.6	1.40	Do.
Kerosene (234°–280°)	5.2	1.57	Do.
Turpentine oil	5.4	1.60	Do.
Lubricating oil 1	46.5	14.10	Slow spreader.
Red oil	54.0	16.32	Do.
Fish oil	66.0	20.00	Do.
Lubricating oil 2	68.0	20.60	Do.
Whale oil	73.0	22.12	Do.
Boiled linseed oil	77.0	23.33	Do.
Raw linseed oil	81.0	24.54	Do.
Cottonseed oil	88.0	26.66	Do.
Lubricating oil 3	99.0	30.00	Do.
Lard oil	103.0	31.51	Do.
Olive oil	104.0	31.82	Do.
Lubricating oil 4	115.0	34.85	Do.
Knochen oil	128.0	35.88	Do.
Lubricating oil 5	177.0	53.66	Do.
Lubricating oil 6	194.0	58.78	Do.
Lubricating oil 7	495.0	150.00	Do.
Castor oil	1,205.0	365.15	Very slow spreader.
Lubricating oil 8	1,472.0	446.06	Do.
Lubricating oil 9	1,740.0	530.30	Do.
Lubricating oil 10	2,340.0	709.09	Do.
Lubricating oil 11	2,610.0	790.90	Do.
Lubricating oil 12	2,707.0	820.90	Do.
Lubricating oil 13	3,568.0	1,081.30	Too slow for effective work.
Lubricating oil 14	5,462.0	1,655.15	Do.
Lubricating oil 15	7,835.0	2,374.27	Do.

PENETRATION OF THE INSECTICIDE INTO THE TISSUES

Shafer (*16*) has shown that contact insecticides, such as kerosene and others of a similar nature, are able to penetrate the tracheæ of an insect, but he considers that it is the vapor from these substances, which is responsible for the killing, inasmuch as the rate at which the liquid itself will pass through the chitin is too slow to account for the death of the insect. He dissolved Sudan III in kerosene to show the passage of the oil through the walls of the tracheæ. At the time of the death of the insect he could find no evidence of a red stain in the tissues, and it was not until the insect had been dead for a long time and the fat bodies had been partially dissolved that he could detect traces of the stain in the tissues. Sudan III, however, is a colloid, and would not be able to pass but very slowly through a semipermeable membrane such as chitin. Thus, the inability of the stain to pass through the chitin did not necessarily imply that the kerosene had not been able to penetrate into the tissues. If the experiment is repeated with picric acid instead of Sudan III, it is found that the tissues are very quickly stained yellow. There are, however, a number of objections to the use of a stain to indicate the

passage of a liquid, as it is quite possible that the stain could penetrate by being absorbed by the walls of the tracheæ without any penetration of the oil. If a few pieces of chitin are placed in kerosene stained with picric acid, they are capable of absorbing practically all the stain from the oil. On the other hand, it is quite possible that the amount of the insecticide which might penetrate and kill the insect would be so small that the amount of stain carried with it could not be detected. Further, it would be impossible to determine the penetration of a vapor by a stain in the insecticide. Chemical tests for insecticides in the tissues in many cases would not be delicate enough for the certain detection of their presence or absence. Finally, after a number of trials, it was found that the best method was to use an indicator for dead tissues. Trypan blue is a water-soluble colloid which does not penetrate the living tissues, but is able to penetrate and stain dead tissues. This was selected as the most suitable indicator. Larvæ of the wax moth were used in these experiments. If a living, untreated larva is opened and the tissues covered with an aqueous solution of trypan blue for a period of two minutes and the stain then removed and the larva examined under water, it will be found that there are particles of the stain adhering along the midintestine, more or less on the silk glands, and along the nerve cord. This does not seem to be a true staining of the tissues, but rather the adherence of particles of the stain, which are difficult to remove by washing (adsorptions).

When an insect has been treated with an effective contact insecticide and opened and stained just before it dies, the tissues which have been killed are stained a deep blue, thus indicating the point of entrance of the poison. No effort was made in this work to determine which tissues were primarily effected by the chemicals. As a counter stain, to show to what extent the materials penetrated the tracheæ, Sudan III was used with the oils and resin with the aqueous solutions. The penetration into the insect of the different insecticides are given in Table III.

TABLE III.—*Penetration of materials as indicated by Sudan III, with trypan-blue method*

FUMIGATION VAPORS

Name.	Time.	Effect.
Nitrobenzene	5½ hours	Blue spots in flat tracheæ to digestive tract only where condensation occurs.
Nicotine	3 hours	Blue along fine tracheæ.
Chlorpicrin	do	Do.
Carbon bisulphid	6½ hours	Do.
		Blue spots along large and fine tracheæ. No condensation noted.

TABLE III.—*Penetration of materials as indicated by Sudan III, with trypan-blue method*—Continued

Name.	Time.	Effect.
NONWETTING SOLUTIONS		
Nicotine solution	1½ hours	Fine tracheæ stained blue. Condensation not noted, but probably present.
Nicotine sulphate	7½ hours	Tissues along large and fine tracheæ stained and blue condensation in flat tracheæ to digestive tract.
Furfurol solution	17 hours	Blue patches on flat tracheæ to digestive tract. Very slight blue along fine tracheæ. Condensation evidently responsible for stains in large tracheæ.
SOAP SOLUTIONS		
Ivory (1 : 800)	31 hours	Blue stain along some of the large tracheæ where red-stained soap solution penetrated.
Soft (1 : 300)	3½ hours	Blue stains along walls of red-stained tracheæ.
VERY VOLATILE OILS AND ACIDS		
Acetic acid	1 hour	Blue spots on large tracheæ and along fine tracheæ. Red-stained and penetrated body wall in thoracic region.
Chlorpicrin	10 minutes	Large and fine tracheæ stained blue. Condensation in large flat tracheæ to digestive tract.
Chloroform	20 minutes	Blue along red-stained tracheæ. Vapor going ahead of red-stained material has little influence. More effect if treated longer.
Gasoline	30 minutes	Passed through tracheæ and partially dissolved fat bodies, but caused little bluing.
VOLATILE OILS AND ACIDS		
Butyric acid	40 minutes	Blue stain along all particularly fine tracheæ. Red stain penetrated body wall as in acetic acid.
Wood creosote	30 minutes	Blue stain along red-stained tracheæ, particularly those to digestive tract.
Kerosene (230°–280°)	2 hours	Blue stain along red-stained tracheæ, particularly those to digestive tract. Blue along some fine tracheæ.
Chlorbenzene		Blue along red-stained tracheæ. No blue or very little beyond red stain.

TABLE III.—*Penetration of materials as indicated by Sudan III, with trypan-blue method*—Continued

ESSENTIAL OILS

Name.	Time.	Effect.
Tar oil	5 hours	Blue along tracheæ to which red penetrated. Very slight blue stain beyond red.
Eucalyptus oil	1½ hours	Blue along red-stained tracheæ but not beyond.
Sassafras oil	2 hours	Blue beyond point of tracheæ to which red penetrated and in a few places along red-stained tracheæ.
Turpentine oil	½ to 1 hour	Red passed through fine tracheæ and into fat bodies. Blue along tracheæ. Red through body wall between segments.

FIXED OILS AND THEIR ACIDS

Paraffin oil	5 to 20 hours	Blue along red-stained tracheæ, but not beyond.
Olive oil	do	Do.
Oleic acid	do	Do.
Peanut oil	do	Do.
Croton oil	do	Do.
Cottonseed oil	do	Do.
Rape-seed oil	do	Do.

LUBRICATING OILS

Lubricating oil 6	5 to 20 hours	Slight blue stain along red-stained tracheæ.
Lubricating oil 1	do	Do.

The insecticides may be divided into four different groups: (1) The nonvolatile insecticides which as liquids penetrate the tracheæ. (2) The volatile insecticides which are able to penetrate the tracheæ as liquids. (3) The volatile insecticides which only penetrate the tracheæ in vapor form. (4) The nonvolatile insecticides which decompose on contact with the insect, producing a vapor which is capable of entering the tracheæ. The results in Table III show that relatively nonvolatile oils pass through the walls of the tracheæ only where the liquid has penetrated.

Soap solutions are particularly interesting, since when a soap is dissolved in water it is hydrolyzed, some of the soap molecules reacting with the water to form sodium hydrate and the free fatty acid. This free fatty acid unites with the fatty acid of that portion of the soap which has not been hydrolyzed, forming a sol (*10*). Since the chitin is a semipermeable membrane, the sol is able to pass through but very slowly into the body of the insect. The sodium hydrate in the solution is no doubt the portion which accounts for death. Experimental

evidence shows that solutions of soaps containing a large percentage of free alkali are more toxic than those which are practically neutral.

Volatile oils and acids show a blue-staining along the walls of the tracheæ where the liquid has penetrated, and also blue blotches along the walls beyond this point. Examination of insects which have been treated for varying lengths of time show that the blue blotches caused by the vapor of the chemical appear more quickly than the blue caused by the penetration of the liquid itself, showing that the vapor is able to penetrate the walls of the tracheæ more quickly than the liquid. It might be noted here that these results are somewhat modified by the fact that the vapor is passing through somewhat thinner chitin than that through which the liquid must pass.

Aqueous solutions such as nicotine do not penetrate the tracheæ other than in the form of a vapor. The blue in this case occurs in blotches along the walls of the tracheæ. What was evidently a condensation of the vapor appeared in the larger tracheæ and the blue staining of the tissues was particularly strong at these points. This confirms the observations of McIndoo (*8*), who has shown by chemical means the condensation of nicotine within the tracheal tubes. When nicotine sulphate comes in contact with the body of the insect, it is slowly decomposed, with the formation of nicotine which enters as a vapor. Such a decomposition is no doubt the explanation of the results of Lovett (*6*), who found that leaves sprayed with nicotine sulphate even when dry are repellent and poisonous to insect larvæ, even though not taken internally.

To such aqueous solutions, which normally are not able to enter the tracheæ, the addition of soap increases their efficiency, as it enables the liquid to spread over the body and enter the spiracles. The addition of too much soap will somewhat decrease the efficiency of the spray, owing to increased cohesion. Some of the results obtained in the use of nicotine sulphate and fish-oil-soap sprays by Smith (*17*) are thus explained.

In general there was little evidence of penetration of the insecticides through the body wall. This does not necessarily mean that the compounds are not able to penetrate the chitin, but that they were unable to do so prior to their entrance by way of the tracheæ. Compounds which are readily soluble in water and readily diffuse in aqueous solutions were frequently found to have gained entrance through the anus and through the mouth. Alcohol, acetic acid, and sometimes soap showed such penetration. The more viscous compounds require very much longer to enter the insect than the compounds with a low viscosity. Lime-sulphur differs from other contact insecticides in its action, but its action has been fully described by Shafer (*16*).

PENETRATION OF FUMIGANTS

As will be noted in Table III, fumigants gain entrance into the insect by way of the tracheæ. In many cases what appeared as a condensation was noticed within the tracheæ and in such cases blue staining, indicating

dead tissues, appeared at these points. These results explain why the volatility of organic compounds should be related to their toxicity (*12*). The more nearly the atmosphere is saturated with the vapor, the more likelihood there is of a condensation in the tracheæ. Even though there is no condensation, the same forces are at work. One of these forces is the tendency for the vapor to condense on coming in contact with the chitinous walls of the tracheæ. The other force is the tendency of the compound to reevaporate from the tracheal walls. In the least volatile this tendency to reevaporate is generally diminished, while in the more volatile compounds, in order to reduce this tendency to reevaporate, very large quantities of the chemical must be present in the air. It is thus apparent that an insect may be killed with comparatively small doses of slightly volatile compounds, while it may require a much heavier dose of a more volatile material. The volatility of organic compounds is therefore, in general, an index of their ability to penetrate into the body of the insect, and inasmuch as the compound which can not penetrate will be unable to kill, it is apparent that the volatility is correlated with the toxicity. One notable exception mentioned in a previous paper (*12*) is that of chlorpicrin, which in very minute quantities is able to kill the insect. In our experiments in tracing the penetration of fumigants it was noticed that this material was able to penetrate the walls of the tracheæ and kill the insect very quickly. This may be due to one of two factors: First, the extreme toxicity of chlorpicrin, or second, an abnormal power of penetration.

The following experiment throws light on this question. Acetic acid and benzene are of about the same volatility as chlorpicrin. On assuming, therefore, for the sake of the experiment, that their powers of penetration are equal, it was determined to test their comparative toxicity to insect tissues. Three living wax-moth larvæ were opened on the ventral side and spread out. One was treated directly with acetic acid, the second with benzene, and the third with chlorpicrin for a period of one-half minute. The chemicals were then quickly removed, and the tissues were washed with water and then treated with trypan blue. The larva treated with acetic acid showed a very intense blue-staining throughout the tissues. The larva treated with benzene showed but slight staining. The larva treated with chlorpicrin showed more staining than benzene but much less than that of acetic acid. Of the three compounds acetic acid was by far the most poisonous to the tissues. In actual fumigation, dipping, or spraying, the death of the insect occurs most quickly with chlorpicrin. This material, therefore, must owe its abnormal toxicity to its ability to be absorbed by the chitin and passed into the body. The reason for this high power of penetration of chitin by chlorpicrin will be the object of further study.

SUMMARY

From the general results reported in this paper it appears that the physical properties as well as the chemical properties have an important bearing upon the efficiency of the contact spray. Even though the spray may contain a very active poison, it will not be effective unless it conforms to certain physical requirements—that is, the ability to vaporize and penetrate in the form of a vapor or to spread over the insect and penetrate in the liquid form. The results reported by McClintock, Houghton, and Hamilton (7) show very clearly that this is true. The results in the use of quassia with or without soap as reported by McIndoo and Sievers (9) are another example, and it is a common observation that the addition of soap to nicotine sprays increases their efficiency. The following are some of the principles which must be kept in mind in studying the effects of contact insecticides.

(1) Contact insecticides may be divided into two groups: (a) Those which spread over the body of the insect and penetrate the tracheæ. (b) Those which are not able to spread over the insect and do not penetrate the tracheæ.

(2) Contact insecticides which are either soluble in ether or chloroform or are fat solvents are able to spread over the insect and enter the tracheæ.

(3) The rate of spread of these insecticides is governed by their viscosity and cohesion.

(4) Compounds with a viscosity as high or higher than castor oil spread so slowly that in general they may be classed as poor insecticides.

(5) Compounds more volatile than xylene evaporate too quickly for effective work.

(6) Sprays in the form of emulsions may enter the tracheæ as such, or the oil remaining after the emulsions is broken down may spread over the insect and enter the spiracles.

(7) Relatively nonvolatile oils penetrate the body of the insect directly through the walls of the tracheæ as liquids, the rate depending upon the viscosity.

(8) Volatile oils may penetrate the walls of the tracheæ in either vapor or liquid form.

(9) Sprays which are unable to enter the tracheæ in liquid form may penetrate and pass through the tracheal walls as vapor.

(10) Fumigants gain entrance and pass through the tracheal walls in vapor form.

(11) Slightly volatile compounds tend to condense upon the tracheal walls, owing to the fact that small quantities are sufficient to saturate the atmosphere. Owing to this high saturation, these condensations tend to penetrate the chitin rather than to reevaporate. Volatility is an index of the ability of the compound to gain entrance into the insect and is therefore closely correlated wiith toxicity.

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INOCULATION EXPERIMENTS WITH SPECIES OF COCCOMYCES FROM STONE FRUITS[1]

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INTRODUCTION

For three years the writer[2] has had under investigation leafspot diseases of cherries and plums (*Prunus* spp.) in Wisconsin. In connection with this work in 1916 and 1917, more than 1,000 cross-inoculation experiments were conducted with *Coccomyces* spp. from a number of the more common wild and cultivated species of Prunus of the State, with the aim of furthering our understanding of the relationships of these pathogenes to their hosts and to one another. This paper is a report of progress on these experiments. It is presented at this juncture because of the temporary discontinuance of the work owing to the stress of war conditions. Final conclusions and the discussion of results in relation to the work of others and in their bearing upon other phases of the leafspot problem are reserved for a future paper.

EXPERIMENTS OF 1916

Preliminary experiments in 1915 and in the spring of 1916, conducted in the light of the results of the similar work of Higgins,[3] formed a basis of experience upon which to develop methods for further work. These tests showed that satisfactory experiments might be conducted either in the greenhouse or out of doors, and that, particularly in the outdoor inoculations, it is essential to have means of maintaining high humidities about the experimental plants or organs without the development of excessively high temperatures. In order that the conditions of the experiments might be as nearly normal as possible, the further inoculations of 1916 were made out of doors. The following method was employed, especial attention being given to standardization of technic, with the aim of increasing both the comparative value and the facility of presentation of results.

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Journal of Agricultural Research,
Washington, D. C.
np

Vol. XIII, No. 11
June 10, 1918
Key No. Wis.-12

56113°—18——2

TECHNIC OF INOCULATIONS

EXPERIMENTAL PLANTS.[1]—In each experiment, the following plants were used: *Prunus cerasus* L. (Montmorency Stark), *P. avium* L. A (Windsor), *P. avium* B (seedling), *P. mahaleb* L., *P. pennsylvanica* L. f., *P. serotina* Ehrh., *P. padus* L., *P. virginiana* L., *P. domestica* L. (Lombard), *P. insititia* L. (Shropshire), *P. americana* Marsh. A (De-Soto), *P. americana* B, *P. salicina* Lindl. (Burbank), *P. munsoniana* Wight and Hedrick (Wild Goose), *Amygdalus persica* L. (Elberta), *A. persica nectarina* Ait. (Boston), *P. armeniaca* L. (Alexander), and *P. besseyi* Bailey.

Except in cases where varietal names are given, the experimental plants were seedlings or cuttings. They were 1-to-2-year-old trees obtained, so far as feasible, from reliable nurseries in the upper Mississippi Valley. *P. americana* and *P. virginiana* were collected in the vicinity of Madison. The identification of all species was confirmed. The trees were assembled in the spring and heeled in until the middle of May, when they were severely pruned and set in the pathological garden in such fashion that suitable groups might be covered by moist chambers. Each group consisted of two rows, 14 inches apart, in which the plants were set at 10-inch intervals, except near the middle, where a 3-foot space was left in order to facilitate the manipulation of the moist compartments. Each plot contained one tree of each experimental species or variety, and in all plots the plants were grouped in the same order. The plots were disposed at intervals of 12 feet in the direction of the rows, and 6 feet laterally. Adjacent to each plot and not nearer than 5 feet to plants to be inoculated was set a group of three controls, one of which was of the species from which the inoculum to be used was to be isolated. Suitable cultivation was provided throughout the season, and the plants grew vigorously.

APPARATUS.—In order to insure favorable humidities and temperatures for infection, it was necessary to devise special apparatus. Accordingly, two movable moist chambers, 6 to 8 feet long, 3½ feet wide, and 3½ to 4 feet high, were constructed so that they could be set over the experimental plants. One was made of glass and wood (see fig. 2), and the other of light galvanized iron over a wooden frame. The latter was provided with glass doors which admitted enough light to keep the plants under fairly normal conditions while covered. These chambers were

[1] In this paper the experimental plants are listed in all cases in the order most advantageous for comparing results from the inoculation tests. When two or more varieties or strains of the same species were used, they were designated, respectively, by appropriate letters (A, B, etc.). In nomenclature Wight's usage was followed where applicable. (WIGHT, W. F. NATIVE AMERICAN SPECIES OF PRUNUS. U. S. Dept. Agr. Bul. 179, 75 p., 4 fig., 13 pl. 1915) The writer wishes to express his indebtedness to Mr. Wight for personal advice in these matters and for verifying the identification of certain species. In varietal names of plums and cherries, the usage of Hedrick was followed. (HEDRICK, U. P. THE PLUMS OF NEW YORK. 616 p., col. pl. Albany, N. Y., 1911. AND HEDRICK, U. P. THE CHERRIES OF NEW YORK. 371 p., col. pl. Albany, N. Y., 1915.)

draped with cheesecloth, which throughout all clear days of operation was kept continuously moist by small streamlets of water from pipes which were conveniently attached to the ridges of the slanting roofs. The evaporation from the cheesecloth, even on the hottest days, kept the temperatures within the chambers below 32° C., while the excess of water kept the soil under them saturated. During the day the temperatures ordinarily ranged between 20° and 28° C., and the relative humidities between 90 and 100 per cent. At night the temperatures were generally lower, while the humidities usually reached or closely approximated saturation. While these chambers gave good results, their weight proved to be a serious practical disadvantage, and in 1917 they were replaced by the much more convenient apparatus described on page 546.

The inocula were applied by means of atomizers, the construction of which was satisfactory and particularly well adapted to steam sterilization.

INOCULA.—When the inocula were procured from cultures, spore suspensions were prepared by introducing sterile distilled water into the culture tubes and teasing the spores into suspension. Such suspensions, suitably diluted with sterile distilled water, comprised the inocula. All cultures used were from single-spore strains. For direct inoculations, spore suspensions were prepared by removing the contents of acervuli by means of sterile scalpels to sterile distilled water, in which they were stirred and suitably diluted.

Just before the inoculations were made, drops of the suspensions to be used were placed on clean sterile glass slides in moist chambers and tested for viability of spores.

METHOD OF INOCULATION.—The inoculations were always made late in the afternoon. The moist chambers already described were placed over the experimental plants and the ground inside was abundantly watered. The inoculum was then applied as spray by means of the sterile atomizers. The chambers were promptly closed and were kept continually wet on the outside by means of the devices already described. Unless otherwise stated, they were always left in place for two days.

Of the controls, series 1 was treated in every way like the inoculated plots, except that sterile distilled water was used instead of an inoculum. The additional special controls, which were located near each plot in the manner already described (p. 540), were left untreated.

RESULTS OF EXPERIMENTS OF 1916

A summary of the experiments of 1916 appears in Table I.

Of the 30 control plants, which included all the experimental species and varieties except *P. padus*, which died, only one, *P. avium*, had developed any infection when the final notes were made on October 14.

Between September 11 and October 14, infection appeared on several leaves of this plant. The lateness of its occurrence and its scarcity, however, make this slight chance infection negligible in the interpretation of the season's results. This conclusion is further justified by the fact that the scores of inoculated trees which did not develop infection may be considered as supplementary controls.

The results of these inoculations, as is witnessed by the abundant infection of the more susceptible plants in series 4, 5, 6, and 7, show that the conditions of the experiments were favorable for infection. There was no indication, however, that these conditions were markedly abnormal or that they should be expected to predispose the plants to infection.

The infection in 1916 was uniformly distinctly less severe than in 1917 (Tables I–VIII). While the reasons for this fact are not yet fully understood, there is considerable evidence to indicate that one or both of the following factors may have been concerned: (1) The probable diminution in pathogenicity of the parasites in question after a considerable period in culture, and (2) a less vigorous germination of their spores in concentrated than in dilute suspensions.

There is considerable evidence (Tables I–VIII) that a relatively long period in culture tends to lessen the pathogenicity of the fungi under investigation, although in vigorously sporulating fresh cultures they are highly pathogenic. This evidence, however, is neither sufficiently extensive nor consistent to warrant final conclusions, and it would appear that other factors than the mere age of a strain in culture are concerned. Cultures of the same age and from the same source may, for instance, vary greatly in the vigor of their sporulation, and consequently in their effectiveness as sources of inocula.

Experiments, the details of which are reserved for a later paper, have shown conclusively that in laboratory tests spores may fail to germinate in a moderately dilute suspension, while in a more dilute portion of the same suspension under like conditions vigorous germination may occur. This condition was not fully apprehended when the experiments of 1916 and the earlier greenhouse series of 1917 were conducted, though the germination experiments in connection with these series show that the suspensions used could not have been excessively concentrated. In all subesquent experiments great care was taken to guard against too great concentration of the inocula. It is hoped that further attention may be given to these problems.

The detailed results of the inoculations are best apprehended by a perusal of the tables. To facilitate this end, the same form and headings and, so far as feasible, the same footnotes have been used in Tables I to VIII.

TABLE I.—*Summary of inoculation experiments with Coccomyces spp., Madison, Wis., 1916*

INOCULATIONS [a]

Series.	Date.	Inoculum.					
		Original host.	Spores.	Source.	Age of strain in culture.	Germination after 2 days.[b]	
						Per cent.	Vigor.
					Months.		
1	July 14			Not inoculated			
2	July 3	*P. domestica*	Conidia	14-day-old culture	10.5	10	+
3	Aug. 28	*P. serotina*	do	*P. serotina*, leaves, Madison.		50	+
4	July 10	*P. mahaleb*	do	14-day-old culture	10.9	10	+
5	July 18	*P. virginiana*	do	*P. virginiana*, leaves, Sturgeon Bay.		3	+
6	July 20	*P. cerasus*	do	14-day-old culture	14.2	95	++
7	Aug. 18	*P. avium*	do	13-day-old culture	3.1	95	+

RESULTS

Plant and treatment.	Infection.[c, g]						
	Series 1 (not inoculated).	Series 2 (inoculum from *P. domestica*).	Series 3 (inoculum from *P. serotina*).	Series 4 (inoculum from *P. mahaleb*).	Series 5 (inoculum from *P. virginiana*).	Series 6 (inoculum from *P. cerasus*).	Series 7 (inoculum from *P. avium*).
Inoculated:							
P. cerasus		**0**	**0**	*4*	*0*	*f* 1	*i* 2
P. avium A		**0**		*3*	*0*		
P. avium B		**0**	**0**	*4*	*0*	*f* 3	*i* 4
P. mahaleb			*2*	*2*	*3*	*f* 1	*i* 2
P. pennsylvanica		**0**	**0**	*d* 0	*0*	*e* 0	
P. serotina		**0**		*0*	*0*	*0*	
P. padus		**0**					
P. virginiana		**0**	**0**		*4*	*0*	*0*
P. domestica		*i* 2	**0**	*0*	*0*	*0*	
P. insitilia		*i* 2	**0**	*0*	*f* 2	*0*	*0*
P. americana A		**0**	**0**	*0*	*0*	*0*	*0*
P. americana B		**0**	**0**	*0*	*0*	*0*	*0*
P. salicina		**0**	**0**	*0*	*0*	*0*	*0*
P. munsoniana		**0**	**0**	*0*	*0*	*f* 4	*e* 0
A. persica		**0**	**0**	*0*	*0*	*0*	*0*
A. persica nectarina		**0**	**0**	*0*	*0*	*0*	*0*
P. armeniaca		**0**	**0**	*0*	*0*	*0*	*0*
P. besseyi		**0**	**0**	*0*	*0*	*f* 4	*f* 4
Not inoculated:							
P. cerasus	*0*						
P. avium B	*h* (?)	*0*		*0*			*0*
P. mahaleb	*0*	*0*		*0*		*0*	
P. pennsylvanica	*0*						
P. serotina	*0*						
P. virginiana	*0*				*0*		
P. domestica	*0*	*0*			*0*	*0*	*0*
P. insitilia	*0*						
P. americana A	*0*						
P. americana B	*0*		*0*	*0*			
P. salicina	*0*						
P. munsoniana	*0*						
P. cerasifera	*0*						
A. persica	*0*						
A. persica nectarina	*0*						
P. armeniaca	*0*						

[a] For details of technic, see p. 540.

[b] Approximate vigor is arbitrarily represented by symbols, as follows: −= weak; += vigorous; ++= very vigorous. Percentage of germination estimated.

[c] Severity of infection is indicated by numbers, as follows: 1= scattered, usually 1 or 2 lesions per leaf; 2= general, averaging 2 to 5 per square inch of leaf surface; 3= general, averaging 6 to 15 per square inch of leaf surface; 4= general, averaging 16 to 50 (estimated) per square inch of leaf surface; and 5= general, averaging more than 50 (estimated) per square inch of leaf surface. In cases where the infection on a given plant was not uniform, only the more severely affected leaves were considered (Pl. 55). The negative results of series in which the maximum infection is represented by a number less than 3 are printed in **bold-face** type, and are not included in the summary (Table IX). All other results, unless otherwise noted, are printed in *italic* type and are included in the summary.

[d] After a prolonged incubation period small brownish flecks appeared (see p. 544).

[e] After a prolonged incubation period spots developed, but the fungus failed to fructify (see p. 544).

[f] Incubation period prolonged.

[g] The final notes were made on October 14.

[h] See discussion on p. 542.

[i] Secondary infection was abundant.

The fungus from *P. domestica* (series 2) induced infection only on *P. domestica* and *P. insititia*. The low degree of infection on the original host, however, makes it unsafe to place confidence in the negative results of this series (compare Table VI and see footnote c, Table I). It is probable that diminished pathogenicity of the fungus in culture, in connection with other factors not yet fully understood, is responsible for the relative sparseness of this infection.

In series 3 the fungus from *P. serotina* infected only *P. mahaleb*. Had *P. serotina* of this bed lived, it would undoubtedly have been abundantly infected (compare Table VIII).

The fungus from *P. mahaleb* (series 4) induced abundant infection on *P. avium* and *P. cerasus* and relatively sparse infection on *P. mahaleb*. After a prolonged incubation period, small flecks appeared on the inoculated leaves of *P. pennsylvanica*, but no spots developed, and the fungus did not fructify. The slow development upon inoculated leaves of flecks or small spots upon which there was no fungal fructification was of fairly common occurrence in these experiments. While satisfactory histological studies of such lesions have not yet been completed, the available evidence indicates that such cases (adequately controlled) may be considered as aberrant infection. Such infection appears to occur commonly only in the case of cross inoculations which rarely, if ever, result in typical infection. Flecking and spotting of this type, furthermore, were much more common in the greenhouse inoculations late in the summer when the plants were weakening than in outdoor experiments. The gradation of this apparently aberrant infection into normal infection made it necessary to adopt a criterion of infection. Accordingly fructification of the fungus was adopted as the most conveniently workable criterion which suggested itself. Unless the fungus fructified, therefore, results are recorded as negative, with annotations regarding flecking or spotting.

In series 4 the infection was more severe than in series 2, despite the fact that the inoculum was from a strain which had been slightly longer in culture than that used in series 2. This is in accord with the belief already expressed that other factors than the age of a strain in culture may influence the diminution of its pathogenicity. In this case, for instance, the strain from *P. mahaleb* had maintained its ability to sporulate in culture in a much higher degree than had that from *P. domestica*. To avoid such complications, the later inoculations were made, so far as feasible, with recently isolated, vigorously sporulating strains. It should be noted, however, that the slow growth of these fungi in culture offers a serious handicap in this regard, as a period of one to two months is ordinarily necessary for isolating a single-spore strain and growing it in sufficient quantity to furnish the necessary inoculum.

In series 5 the fungus from *P. virginiana* induced abundant infection on its original host, moderate infection on *P. mahaleb*, and light, delayed infection on *P. insititia*.

In series 6, inoculated with a 14-month-old strain from *P. cerasus*, infection was rather sparse and somewhat slow in developing, despite the fact that the inoculum contained abundant, vigorously viable spores. Abundant infection developed on *P. avium* and sparse infection on *P. cerasus* and *P. mahaleb*. Rather abundant infection developed after a more prolonged incubation period on *P. munsoniana* and *P. besseyi*.

The fungus from *P. avium* (series 7) infected *P. avium* abundantly and *P. cerasus* and *P. mahaleb* rather sparsely. After a prolonged incubation period, *P. besseyi* also developed abundant infection.

Numerous reisolations were made in the same manner as in 1917 (p. 563), and with like results.

EXPERIMENTS OF 1917

In 1917 the outdoor tests were supplemented by extensive greenhouse experiments. By starting potted plants early in the spring, it was found possible to have them in leaf as soon as the ascospores of the fungi under investigation approached maturity (their maturity can be hastened in the laboratory). Thus, it was possible to conduct extensive experiments, without danger of natural infection, before the outdoor plants were ready. In this way essentially the equivalent of two years' data was secured in one season. Furthermore, it was possible to study infection under varied experimental conditions more readily in the greenhouse than out of doors. The danger of falling into errors of interpretation of the results obtained under greenhouse conditions seems adequately guarded against by the extensive outdoor tests of two seasons.

TECHNIC OF INOCULATIONS

OUTDOOR EXPERIMENTS

EXPERIMENTAL PLANTS.—The following plants were used: *Prunus cerasus* (Montmorency Stark), *P. avium* (Yellow Spanish), *P. mahaleb*, *P. pennsylvanica*, *P. serotina* A, *P. serotina* B, *P. serotina* C, *P. padus*, *P. virginiana*, *P. domestica* (Lombard), *P. insititia* (Damson Shropshire), *P. americana* A (De Soto), *P. americana* B, *P. salicina* (Burbank), *P. munsoniana* (Wild Goose), *Amygdalus persica* (Elberta), *P. armeniaca* (Superba), and *P. besseyi*.

Two consignments of *P. serotina* which were received under erroneous labels were included in the experiments for purposes of comparison. Plants of *P. serotina* were accordingly distinguished as to source by the letters "A," "B," and "C."

Except in cases where varietal names are given, the experimental plants were seedlings or cuttings. They were obtained, assembled, and

heeled in in accordance with the method adopted in the preceding year's work (p. 540). *P. pennsylvanica* and *P. virginiana* were collected in the vicinity of Madison. In late May, after being severely pruned, the plants were set in a convenient field, well removed from any known source of natural inoculum of the *Coccomyces* spp. under investigation. The plants to be inoculated were set in groups, each of which contained all of the experimental species and varieties, conveniently disposed for covering with a moist chamber. They formed in each plot two rows, 14 inches apart, with 10-inch intervals between plants in the rows. A similarly arranged group of control plants was placed 6 feet from one end of each of these plots. The number and identity of the controls varied with the inocula to be used. It was planned to have in each control group a cultivated cherry, a wild cherry, and a plum, including the host from which the inoculum to be used was to be secured. Further controls were added as the available supply of plants permitted. Inasmuch as cross-inoculation tests with *Cladosporium* spp. on certain species of Prunus were being conducted at the same time, the plants to be inoculated with *Cladosporium* spp. were set with the controls of the Coccomyces inoculations. Thus, they served as additional controls for the latter series, the inoculated plants of which, in turn, served as controls for the Cladosporium series. All beds were at least 6 feet apart. Suitable cultivation was provided throughout the season, and the plants which took root grew vigorously. However, owing to the bad condition in which some of the nursery stock arrived, many plants failed to take root. This marred considerably the completeness of the experiments.

APPARATUS.—The moist chamber illustrated in figure 1 was used to cover the inoculated plants, while a smaller chamber of similar construction covered the controls. This latter chamber was 3½ feet wide, 6 feet long, and 4½ feet high. Its roof, however, was pyramidal, rising to a peak upon which the play of a single nozzle provided an adequate supply of water. These chambers were connected by a 100-foot hose to faucets conveniently located on a temporary pipe line. They were easily handled by two men, and were very satisfactory.

In series 1, A–D, in which the plants were inoculated in their natural habitat, a bell jar lined with moist paper towels was placed over each plant.

The inocula were applied by means of sterile atomizers equipped with 8-ounce containers and long intake tubes. In some of the experiments the atomizers were operated by compressed air from a small portable drum, the pressure being regulated by a cut-off. The atomizers were connected with the drum by a 10-foot length of silk-covered rubber tubing. This apparatus gave very good results until a defect in the drum led to its disuse. A light drum with a capacity of 6 to 10 cubic feet, constructed to withstand a pressure of at least 30 pounds, and con-

veniently mounted on a small truck which will easily pass through standard doorways, will probably be much more satisfactory. A supply of compressed air with which to charge such apparatus is highly desirable, since charging it by means of an automobile pump is as laborious and time-consuming as atomizing by hand.

INOCULA.—The inocula were prepared in the same fashion as in the experiments of 1916 (p. 541), except that in a few cases the cultures used were not from single-spore strains. In all cases, however, the isolations were made by the method previously described by the writer,[1] their purity being established by frequent microscopic examinations in their

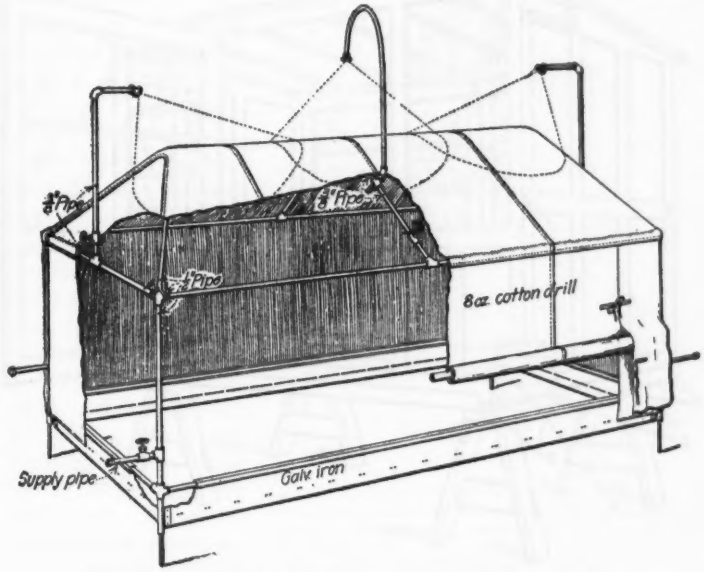


FIG. 1.—Moist chamber used in the outdoor inoculation experiments of 1917.

early stages of development and by later cultural tests. Inasmuch as no differences were observed between the results from single- and multiple-spore cultures, the strains are not distinguished in this regard in the tables.

METHOD OF INOCULATION.—The plants were inoculated by the method used in 1916 (p. 541). The moist compartments, however, were left in place only one day.

Before each inoculation, in order to facilitate the taking of records, markers of white string were tied near the apexes of several twigs on each plant. In this way the results of successive inoculations on the same

[1] KEITT, G. W. SIMPLE TECHNIQUE FOR ISOLATING SINGLE-SPORE STRAINS OF CERTAIN TYPES OF FUNGI. *In* Phytopathology, v. 5, no. 5, p. 266–269, 1 fig. 1915.

plants were usually readily differentiated, such inoculations being made on the recently developed foliage of the rapidly growing twigs.

GREENHOUSE EXPERIMENTS

EXPERIMENTAL PLANTS.—The experimental plants were from the same sources and of the same species and varieties as those used in the outdoor tests (p. 545). They did not, however, include all the species used in the field. The plants were assembled in early April, severely

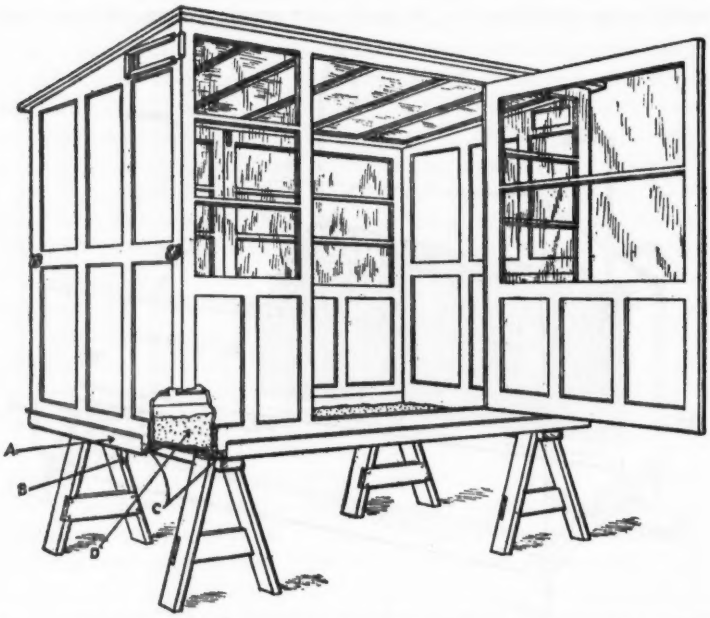


FIG. 2.—Moist chamber used in the greenhouse inoculation experiments: *A*, galvanized-iron pan, with drainage outlet *B*; *C*, strips of board to support chamber; *D*, sphagnum or sand. Dimensions: Length, 6 feet; breadth, 32 inches; height of front, 4½ feet. This chamber was also used in the outdoor inoculations of 1916 (p. 540).

pruned, and set in 6- to 10-inch flowerpots. The pots were submerged in the soil in a greenhouse of the garden type, and the plants were given suitable cultural attention. To inhibit the development of insect pests, particularly the red spider, the plants were washed daily with a strong spray from an angle nozzle conveniently connected with the water supply. Throughout the early spring the temperature of this greenhouse ordinarily ranged between 21° and 27° C. In late spring and early summer the maximum temperature was frequently considerably higher.

APPARATUS.—Suitable conditions of humidity were obtained by placing the inoculated plants in the moist chamber illustrated in figure 2.

While, in order to avoid excessively high temperatures, it was necessary to screen this chamber against direct sunlight, the experimental plants received a good supply of diffuse light. This apparatus gave very satisfactory results, maintaining a humidity which closely approximated saturation.

All spore suspensions were applied by atomizers, as in the outdoor series (p. 547).

In making inoculations with ascospores, application of the spores by means of natural discharge of the asci was by far the most satisfactory method tried. This was accomplished by adaptation of methods which have been used by others.[1] The simple device used is illustrated in figure 3. The washers were cut from gasket rubber by means of cork borers, which were also used for cutting the ascogenous leaf fragments. The cover glasses were standard No. 2 squares (22 mm.). The clips were made from No. 24 brass wire, and furnished a grip which, while adequate for holding the apparatus in place, was not strong enough to injure the leaves. These devices gave very satisfactory results (Pl. 59, C, D).

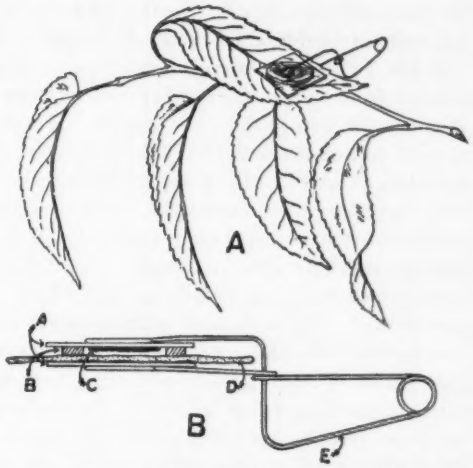


FIG. 3.—Device used for inoculation by means of natural ejection of ascospores: *A*, on *P. americana*; *B*, in cross section (see text). *a*, cover glass; *b*, rubber washer; *c*, ascogenous leaf fragment; *d*, leaf to be inoculated; *e*, clip.

INOCULA.—Unless otherwise noted, all inocula were prepared like those of the outdoor experiments (p. 546).

METHOD OF INOCULATION.—In all series inoculated with spore suspensions the experimental plants were removed to the pathologium,[2] where they were sprayed in the same manner as the outdoor series (p. 547) and placed in the moist chamber. Similarly, in the inoculations by discharge of asci, the experiments were set up in the pathologium, and the plants were then promptly placed in the moist compartment. The inoculations were made on the lower (dorsal) surfaces of the leaves, which were left in such position that the spores might be discharged downward upon them rather than upward. This was easily accomplished after the plants had

[1] Particularly helpful suggestions in this regard were kindly given by Dr. F. R. Jones, now Pathologist, Cotton, Truck, and Forage Crop Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture, and by Prof. James Johnson, of the University of Wisconsin.

[2] Pathologium: A phytopathological laboratory used in conjunction with a greenhouse.

been placed in the moist chamber by propping the leaves against adjacent leaves or twigs (fig. 3). Ordinarily several cells were placed upon each plant, and in order to increase the number of trials, they were moved at suitable times to other leaves. By shifting the cells from one plant to another within the series when these changes were made, the chances of failure of discharge of spores upon any given plant were minimized. Just before each experiment was begun, each leaf fragment of the ascogenous material to be used was tested for spore discharge, and unless spores were being discharged abundantly the material was rejected. Even with these precautions, however, it was not possible to insure a satisfactory inoculum in every case. Therefore, full confidence can not be placed in each individual negative result. Great care was exercised to maintain within the cells favorable conditions of humidity for discharge of the asci. The leaf fragments, bearing fresh, open ascocarps, were always taken directly from the moist chambers. They were wet just enough to make them adhere well to the cover glasses. A white string about the petiole of each inoculated leaf served as a marker, and in each series all the inoculations were made on approximately the same part of the leaf surface, usually, for convenience, near the apex. Freshly discharged ascospores were found to be so uniformly viable that in most cases special germination tests were not made. The inoculated plants were held in the moist chambers for two days, after which they were incubated in the greenhouses. No inoculated plant or other source of possible inoculum was carried into the greenhouse where the uninoculated plants were grown, and the various inoculated series were kept well apart in the other greenhouses, in order to minimize the possibilities of chance infection. In these greenhouses throughout the early spring the temperatures ordinarily ranged between 24° and 29° C. In late spring and early summer the maximum temperatures were considerably higher, but not excessive. In late July and August, despite careful attention to shading and ventilation, the temperatures at times became excessive. The more important aspects of the experiments, however, were completed before this time.

The control plants were sprayed with sterile distilled water, and held in the moist chamber for two days.

RESULTS OF EXPERIMENTS OF 1917

The results of the experiments of 1917 are summarized in Tables II to VIII.

Of the scores of control plants of both the outdoor and the greenhouse series, including representatives of all the species and varieties used, not one developed a single infection throughout the entire season. Futhermore, the many inoculated plants upon which no infection occurred serve as additional controls. It is evident, therefore, that the experiments were adequately and satisfactorily guarded against chance infec-

tion. The remoteness of the experimental plants from infected species of Prunus apparently precluded chance natural infection by ascospores, while the delicate nature of the conidia of these fungi, and their methods of dissemination and infection, account in large measure for the lack of spread of the disease from plants of one series to those of another.

The abundant infection which occurred on susceptible plants both in the outdoor and the greenhouse series proves conclusively that the conditions of the experiments were favorable for infection. There was, however, no evidence to indicate that these conditions were such as to predispose the experimental plants to infection, with the possible exception of some cases of infection in the greenhouse after much prolonged incubation periods and after the experimental plants had become somewhat lowered in vitality. Under such conditions rare or difficult crosses occurred more freely in the greenhouse than outside, and in several such cases crosses which have not been duplicated outdoors were effected in the greenhouse. Such results are interpreted in the light of these facts and are suitably annotated in the tables. With these exceptions, the results of the greenhouse series closely parallel those of the outdoor experiments, and appear to be fully reliable.

The results of the year's inoculations are best apprenended by a study of Tables II to VIII. Each table contains a summary of all the inoculations with strains obtained from one host. By reading down the columns of the lower section, one may quickly trace the results by series, while, by reading across columns, he may compare the results of all the series on any species. The details regarding inoculations may be ascertained by reference to the upper section of the table.

TABLE II.—*Summary of inoculation experiments with Coccomyces spp. from Prunus cerasus, Madison, Wis., 1917*

INOCULATIONS [a]

Location and series.	Date.	Inoculum.						
		Spores.	Source.	Age of strain in culture.	Method of application.	Germination. [b]		
						After hours.	Per cent.	Vigor.
Out of doors:				*Months.*				
1A	June 8	Ascospores.	Leaves, Madison		Dehiscence.			
10	Aug. 17	Conidia	11-day-old culture	1.7	Spray	24	5	+
15	Sept. 19	do	10-day-old culture [i]	1.8	do	24	1	+
In greenhouse:								
101	May 9	do	20-day-old culture	7.6	do	20	60	+
101	June 2	Ascospores.	Leaves, Madison		Dehiscence.			
101	July 2	Conidia	20-day-old culture	1.0	Spray	17	50	++
104	May 16	do	14-day-old culture	7.8	do	20	90	++
104	June 5	Ascospores.	Leaves, Madison		Dehiscence.			
104	June 26	Conidia	22-day-old culture	.7	Spray	24	1	+
104	July 15	do	15-day-old culture	1.3	do	24	1	+
106	May 19	Ascospores.	Leaves, Madison		Spray [k]	48	Trace	−
106	June 9	do	do		Dehiscence.			

[a] For details of technic, see p. 545.
[b] See footnote b, Table I.
[i] This strain was reisolated from *P. cerasifera* of series 104.
[k] Crushed ascocarps in sterile distilled water.

TABLE II.—*Summary of inoculation experiments with Coccomyces spp. from Prunus cerasus, Madison, Wis., 1917*—Continued

RESULTS

Plant and treatment.	Infection. *e*, *g*										
	Out of doors.			In greenhouse.							
	Series 1A. [h]	Series 10.	Series 15.	Series 101 from inoculation of—			Series 104 from inoculation of—				Series 106 from inoculation of—	
				May 9.	June 2.	July 2.	May 16.	June 5.	June 26.	July 15.	May 19.	June 9.
Inoculated:												
P. cerasus		*5*	*4*	0	*5*	*5*	0	*4*	*4*	*5*	0	*4*
P. mahaleb			*4*	0	*0*	*3*	*1*	*3*	*4*	*4*	*1*	*3*
P. pennsylvanica	*d* 0											
P. serotina A			0									
P. serotina B		0	0	0	*0*	*0*	0	*0*	*0*	*0*	0	*0*
P. serotina C		0										
P. padus		0										
P. virginiana	0	0		0	*0*	*0*	0	*0*	*e* 0	*0*	0	*0*
P. domestica		0	0	0	*e* 0	*e* 0	0	0	*e* 0	*e* 0	0	*e* 0
P. insititia		0	0	0	*f* (?)	*f* 3	0	(?)	*f* 4	*f* 4	0	*f* 3
P. americana A		0	0									
P. americana B		0	0	0	*d* 0	*d* 0	0	0	*d* 0	*d* 0	0	*d* 0
P. salicina		0	0	0	*e* 0	*e* 0	0	0	0	0	0	*e* 0
P. munsoniana			0	0	*f* 3	*f* 3	0	(?)	(?)	*f* 4	0	*e* 0
A. persica		0	0	0	*0*	*0*					0	*0*
P. besseyi		0	0									
P. mahaleb (*P. cerasus* stock)							0	*2*	*3*	*5*		
P. cerasifera (*P. domestica* stock)							0	(?)	(?)	*f* 4		
Not inoculated:												
P. cerasus		0	0	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
P. americana B		0	0									
P. domestica		0	0									
P. mahaleb			0									
P. pennsylvanica	0		0									
P. serotina			0								0	0
A. persica		0	0									
P. virginiana	0											

c–*f* See footnotes c to f, Table I.

g The final notes on inoculations of 1917 were made on the following dates: Series 1 A–D, June 26; all other outdoor series, October 15; all greenhouse series, August 18.

[h] See discussion, p. 551.

f In cases where it was not possible to differentiate the results of successive inoculations on the same plant, the combined results of all the inoculations in question are printed in italic type, under the heading of the last inoculation in question, with the appropriate footnote, d, e, or f, and the earlier indistinguishable results are recorded in **bold-face** type.

DISCUSSION OF TABLE II

Abundant infection resulted from all inoculations except the following: Series 1A; series 101, May 9; series 104, May 16; and series 106, May 19. The absence of infection in series 1A was evidently due to the fact that this series contained no susceptible plant. Lack of virulence of the inocula probably accounts for the failures in series 101 and 104, the strain used having been more than seven months in culture. In series 106 the inoculum was evidently unsatisfactory, only a trace of germination occurring in the laboratory test. In these and like series, therefore, except series 1A, the negative results are without value and are excluded from the summary (Table IX), while the positive results are not comparable in regard to the severity of infection with those obtained

from inoculations made under more favorable conditions. Consequently such positive results are left out of account in computing the average degrees of infection (Table IX. See footnote c, Table I).

P. cerasus was uniformly abundantly infected (Pl. 59, A), while on *P. mahaleb* (Pl. 56, C) the infection was only slightly less severe. In the greenhouse, after prolonged incubation periods, *P. insititia* (Pl. 56, B) consistently developed infection, but this cross did not occur in the field trials. With *P. munsoniana* (Pl. 56, D) similar results were obtained. In 1916, after prolonged incubation (Table I), this cross led to infection in the field. The single greenhouse test with *P. cerasifera* (Pl. 56, A) led to delayed infection. On the other inoculated plants and on the controls (Pl. 59, B), no infection developed, though in the greenhouse after prolonged incubation periods small spots developed in considerable abundance upon *P. domestica* (Pl. 56, E) and *P. salicina* and flecks upon *P. americana* B. Similarly, flecks developed upon *P. pennsylvanica* out of doors (see p. 544). In none of these cases, however, did fructification of the fungus accompany these developments.

DISCUSSION OF TABLE III

No infection resulted from the first inoculation of series 102, and only slight infection on *P. cerasus* was induced by the first inoculation of series 14. From all the other inoculations moderate infection developed, but in no case was it severe. The causes of these variations are not fully understood. It seems probable that this generally low degree of infection was due, in considerable part at least, to a diminution in the pathogenicity of the fungus in culture, since a single strain, more than a year old, was used for all these experiments. Such reduction in pathogenicity, however, would not explain the differences in the results of the first and the subsequent inoculations of series 102. It is possible that temperature variations in the greenhouses during the course of these experiments may have been an important factor, as temperature differences might well cause more conspicuous variations in the case of a strain of reduced pathogenicity than with a virulent strain. It should also be remembered that, owing to the failure of *P. avium* stock to root, the original host was not included in these tests. These matters, however, are subjects for further investigation.

Infection occurred consistently on *P. cerasus* and *P. mahaleb*. None of the other experimental plants were infected, though in certain cases, after prolonged incubation periods, spots developed upon *P. padus*, *P. domestica*, *P. insititia*, and *P. munsoniana*, and flecks appeared on *P. americana* A and B and *P. salicina*.

TABLE III.—*Summary of inoculation experiments with Coccomyces spp. from Prunus avium, Madison, Wis., 1917*

INOCULATIONS [a]

Location and series.	Date.	Inoculum.				Germination. [b]		
		Spores.	Source.	Age of strain in culture.	Method of application.	After hours.	Per cent.	Vigor.
Out of doors:				*Months.*				
11	July 30	Conidia	9-day-old culture	14.5	Spray	24	75	+
11	Aug. 29	do	14-day-old culture	15.5	do			
14	Aug. 3	do	11-day-old culture	14.6	do	17	90	+
14	Sept. 12	do	12-day-old culture	15.9	do	24	95	+
In greenhouse:								
102	May 12	do	9-day-old culture	11.9	do	20	50	+
102	May 24	do	15-day-old culture	12.3	do			
102	July 2	do	18-day-old culture	13.6	do	17	75	+

RESULTS

Plant and treatment.	Infection. [c, g]						
	Out of doors.				In greenhouse.		
	Series 11 from inoculation of—		Series 14 from inoculation of—		Series 102 from inoculation of—		
	July 30.	Aug. 29.	Aug. 3.	Sept. 12.	May 12.	May 24.	July 2.
Inoculated:							
P. cerasus	3	3	[h] 2	[h] 3	0	4	4
P. mahaleb	1	3	0	3	0	3	3
P. pennsylvanica	0	0	0	0			
P. serotina A	0	0	0	0			
P. serotina B	0	0	0	0	0	0	0
P. serotina C			0	0			
P. padus	[e] 0	0	0	0			
P. virginiana	0	0			0	0	0
P. domestica	0	0	0	0	0	0	[e] 0
P. insitilia	0	0	0	0	0	0	[e] 0
P. americana A	[d] 0	0	0	0			
P. americana B	[d] 0	0	0	0	0	0	[d] 0
P. salicina	0	0	0	0	0	0	[d] 0
P. munsoniana	0	0	0	0	0	0	[e] 0
A. persica	0	0	0	0	0	0	0
P. armeniaca	0	0					
P. besseyi	0	0	0	0			
Not inoculated:							
P. cerasus	0	0	0	0	0	0	0
P. domestica	0	0	0	0	[f]		
A. persica	0	0	0	0			
P. americana B	0	0	0	0			
P. virginiana	0	0					
P. salicina			0	0			
P. serotina			0	0			
P. padus	0	0					
P. avium	0	0					
P. armeniaca	0	0					

[a] See footnote a, Table II.
[c] See footnotes b to e, Table I.
[g] See footnote g, Table II.
[h] Secondary infection was very abundant.

TABLE IV.—*Summary of inoculation experiments with Coccomyces spp. from Prunus mahaleb, Madison, Wis., 1917*

INOCULATIONS [a]

Location and series.	Date.	Inoculum.						
		Spores.	Source.	Age of strain in culture.	Method of application.	Germination.[b]		
						After hours.	Per cent.	Vigor.
Out of doors:				*Months.*				
7	July 25	Conidia	*P. cerasus* leaves, series 116.	.....	Spray	24	30	+
7	Aug. 16	do	11-day-old culture	2.4	do	24	− 1	−
8	July 26	do	*P. mahaleb* leaves, series 116.	.....	do	20	50	+
8	Aug. 8	do	12-day-old culture	2.1	do	48	25	+
18	Sept. 22	do	15-day-old culture	3.5	do	17	0	.....
In greenhouse:								
115	June 30	do	24-day-old culture	.8	do	15	50	+
115	July 10	do	10-day-old culture	1.1	do	45	5	+
115	July 26	do	*P. mahaleb* leaves, series 116.	.....	do	20	50	+
116	July 4	do	20-day-old culture	1.0	do	.....	.....	.....
116	July 12	do	11-day-old culture	1.3	do	48	−1	−

RESULTS

Plant and treatment.	Infection. [c, g]									
	Out of doors.					In greenhouse.				
	Series 7 from inoculation of—		Series 8 from inoculation of—		Series 18.	Series 115 from inoculation of—			Series 116 from inoculation of—	
	July 25.	August 16.	July 26.	August 8.		June 30.	July 10.	July 26.	July 4.	July 12.
Inoculated:										
P. cerasus	4	4	4	4	4	3	5	3	4	4
P. avium	.....	.....	5	5	.....	.....	.....	.....	.....	.....
P. mahaleb	h 3	h 3	h 2	h 2	3	2	2	4	3	3
P. pennsylvanica	2	1	f 3	4	.....	.....	.....	.....	.....	.....
P. serotina A	0	0	0	0	.....	.....	.....	.....	.....	.....
P. serotina B	.....	.....	0	0	.....	0	0	0	0	0
P. serotina C	0	0	0	0	.....	.....	.....	.....	.....	.....
P. padus	e 0	e 0	e 0	e 0	0	.....	.....	.....	.....	.....
P. virginiana	0	.....	0	0	.....	0	0	0	0	0
P. domestica	0	0	0	0	0	0	e 0	0	e 0	e 0
P. insititia	0	0	0	0	0	(?)	f 2	0	(?)	f 2
P. americana A	0	0	0	0	0	.....	.....	.....	.....	.....
P. americana B	0	0	0	0	0	0	0	0	0	d 0
P. salicina	0	0	.....	.....	0	.....	.....	.....	.....	.....
P. munsoniana	0	e 0	0	0	0	f 2	f 3	0	(?)	f 3
A. persica	e 0	e 0	0	0	0	0	0	0	0	0
P. armeniaca	0	0	0	0	.....	.....	.....	.....	.....	.....
P. besseyi	0	0	3	0	0	.....	.....	.....	.....	.....
P. mahaleb (*P. cerasus* stock)	.....	.....	.....	.....	.....	.....	.....	.....	3	3
Not inoculated:										
P. mahaleb	0	0	0	0	0	0	0	0	0	0
P. cerasus	0	0	.....	.....	0	.....	.....	.....	.....	.....
P. americana B	0	0	0	0	.....	.....	.....	.....	.....	.....
P. domestica	0	0	0	0	.....	.....	.....	.....	.....	.....
P. virginiana	0	0	0	0	.....	.....	.....	.....	.....	.....
P. armeniaca	0	0	.....	.....	.....	.....	.....	.....	.....	.....
A. persica	0	0	0	0	.....	.....	.....	.....	.....	.....
P. serotina	0	0	0	0	.....	.....	.....	.....	.....	.....

[a] See footnote a, Table II.
[b–f] See footnotes b to f, Table I.
[g] See footnote g, Table II.
[h] Secondary infection was very abundant.

DISCUSSION OF TABLE IV

All the inoculations with strains from *P. mahaleb* induced either moderate or abundant infection. *P. cerasus*, *P. avium*, and *P. mahaleb* were consistently moderately or abundantly infected. The disease was usually slightly less severe on *P. mahaleb* than on the cultivated cherries. This may well be due to the fact that these strains in all likelihood originally passed to *P. mahaleb* from *P. cerasus*, inasmuch as they were isolated from *P. mahaleb* trees which had grown from *P. cerasus* stocks in an old neglected orchard in Door County, where *P. mahaleb* is rarely found. *P. pennsylvanica* was also consistently infected, but less abundantly. In one case *P. besseyi* was infected out of doors. In certain cases, after prolonged incubation in the greenhouse, *P. insititia* and *P. munsoniana* developed infection, while in certain instances spotting occurred on *P. munsoniana*, *P. padus*, *P. domestica*, and *A. persica*. In one case in the greenhouse, flecks developed on *P. americana* B. No other infection occurred.

TABLE V.—*Summary of inoculation experiments with Coccomyces spp. from Prunus pennsylvanica, Madison, Wis., 1917*

INOCULATIONS [a]

Location and series.	Date.	Inoculum.				Germination.[b]		
		Spores.	Source.	Age of strain in culture.	Method of application.	After hours.	Per cent.	Vigor.
Out of doors:				*Months.*				
1B	June 8	Ascospores	Leaves, Sturgeon Bay.	.....	Dehiscence.	.....	.....	.....
6	July 24	Conidia	9-day-old culture	1.7	Spray	20	5	−
6	Aug. 4	do	8-day-old culture	2.1	do	20	5	−
12	July 31	do	10-day-old culture	2.0	do	17	5	+
12	Aug. 15	do	do	2.4	do	24	1	−
In greenhouse:								
107	May 22	do	do	8.6	do	48	−1	−
107	June 9	Ascospores	Leaves, Sturgeon Bay.	.....	Dehiscence.	.....	.....	.....
107	June 30	Conidia	7-day-old culture	.9	Spray	15	75	++
107	July 13	do	13-day-old culture	1.4	do	18	95	++
107	July 24	do	8-day-old culture	1.7	do	20	5	−
109	May 29	Ascospores	Leaves, Sturgeon Bay.	.....	Dehiscence.	40	80	+
109	June 12	Conidia	*P. pennsylvanica* leaves, series 109.	.....	Spray	48	1	−
109	June 28	do	*P. mahaleb* leaves, series 109.	.....	do	24	50	+

[a] See footnote a, Table II.
[b] See footnote b, Table I.

TABLE V.—*Summary of inoculation experiments with Coccomyces spp. from Prunus pennsylvanica, Madison, Wis., 1917*—Continued

RESULTS

Plant and treatment.	Infection.[c, g]												
	Out of doors.					In greenhouse.							
	Series 1B.	Series 6 from inoculation of—		Series 12 from inoculation of—		Series 107 from inoculation of—					Series 109 from inoculation of—		
		July 24.	August 4.	July 31.	August 15.	May 22.	June 9.	June 30.	July 13.	July 24.	May 29.	June 12.	June 28.
Inoculated:													
P. cerasus	.....	0	0	*f*3	*e*0	0	0	0	*d*0	0	0	0	0
P. avium	.....	.....	.....	3	3	.....	.....	.....	.....	.....	.....	.....	.....
P. mahaleb	.....	.....	.....	2	0	0	4	3	.....	2	3	4	4
P. pennsylvanica	5	3	5	4	3	0	5	.....	3	2	5	5	4
P. serotina A	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. serotina B	.....	.....	.....	0	0	.....	.....	.....	.....	.....	0	0	0
P. serotina C	.....	.....	.....	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. padus	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. virginiana	0	0	0	0	0	0	0	0	0	0	0	0	0
P. domestica	.....	0	0	0	0	0	0	0	0	*d*0	0	0	0
P. insititia	.....	0	0	0	0	0	0	0	0	*d*0	0	*e*0	0
P. americana A	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. americana B	.....	0	0	0	0	0	0	0	0	*d*0	0	0	0
P. salicina	.....	0	0	0	0	0	0	0	0	0	0	0	0
P. munsoniana	.....	0	0	0	0	0	0	0	0	*d*0	(?)	*f*2	0
A. persica	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. armeniaca	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. besseyi	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. cerasifera (*P. domestica* stock)	.....	.....	.....	.....	.....	.....	.....	(?)	(?)	*f*3	.....	.....	.....
Not inoculated:													
P. pennsylvanica	0	0	0	0	0	0	0	0	0	0	0	0	.....
P. serotina B	.....	0	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
P. serotina C	.....	0	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
P. domestica	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. armeniaca	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. americana B	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
A. persica	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. cerasus	.....	0	0	0	0	.....	.....	.....	.....	.....	.....	.....	.....
P. virginiana	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[c-f] See footnotes c to f, Table I. [g] See footnote g, Table II.

DISCUSSION OF TABLE V

The first inoculation of series 107 induced no infection. This was evidently due to the unsatisfactory nature of the inoculum, as is witnessed by its low percentage of germination. This inoculum was secured from a strain that had been more than eight months in culture. The last inoculation of this series caused less abundant infection than was expected. The cause of this fact is not understood. It may possibly be correlated with the high temperatures that developed in the greenhouse in midsummer. All other inoculations with strains from *P. pennsylvanica* caused either moderate or abundant infection. *P. pennsylvanica*, *P. mahaleb* (except in the second inoculation of series 12), and *P. avium* were consistently infected. In one case, after a prolonged incubation period, *P. cerasus* was infected. A single case of delayed infection like-

wise occurred on *P. munsoniana*. The single plant tested of *P. cerasifera* developed fairly abundant delayed infection. No other infection was observed. In certain cases, however, usually in the greenhouse, flecks or spots occurred on *P. cerasus*, *P. domestica*, *P. insititia*, *P. americana* B, and *P. munsoniana*.

TABLE VI.—*Summary of inoculation experiments with Coccomyces spp. from Prunus domestica, Madison, Wis., 1917*

INOCULATIONS [a]

Location and series.	Date.	Inoculum.				Germination. [b]		
		Spores.	Source.	Age of strain in culture.	Method of application.	After hours.	Per cent.	Vigor.
Out of doors:				*Months.*				
5	July 23	Conidia	8-day-old culture	1.6	Spray	24	15	+
5	Aug. 28	do	do	2.9	do	36	80	−
16	Sept. 20	do	14-day-old culture	1.8	do	17	5	+
In greenhouse:								
103	May 14	do	11-day-old culture	20.5	do	20	60	+
103	June 14	do	27-day-old culture	21.5	do			
103	June 30	do	15-day-old culture	.9	do	15	50	+
110	June 1	Ascospores	Leaves, Sturgeon Bay.		Dehiscence	24	80	+
110	June 30	Conidia	15-day-old culture	.9	Spray	15	50	+
110	July 15	do	do	1.3	do	24	75	+

RESULTS

Plant and treatment.	Infection. [c, g]								
	Out of doors.			In greenhouse.					
	Series 5 from inoculation of—		Series 16.	Series 103 from inoculation of—			Series 110 from inoculation of—		
	July 23.	Aug. 28.		May 14.	June 14.	June 30.	June 1.	June 30.	July 15.
Inoculated:									
P. cerasus	0	0	0	0	0	0	0	0	
P. mahaleb	0	0		0	0	f 3	0	1	1
P. pennsylvanica	0	0							
P. serotina A	0	0							
P. serotina B	0	0	0	0	0	0	0	0	0
P. serotina C	0	0							
P. padus	d 0	d 0	0						
P. virginiana	0	0		0	0	0	0	0	0
P. domestica	4	4	4	2	2	5	h 0	5	
P. insititia	4	4	4	1	2	5	3	5	
P. americana A	4	2	2						
P. americana B	4	2	4	0	0	4	3	5	
P. salicina	e 0	e 0	0	0	0	f 4			
P. munsoniana	0	0	0	0	0	f 4	0	0	e 0
A. persica	0	0		0	0	f 1	(?)	f 1	
P. armeniaca	0	0							
P. besseyi	(?)	f 1							
Not inoculated:									
P. domestica	0	0	0				0	0	0
P. americana B	0	0		0	0	0			
P. cerasus	0	0							
A. persica	0	0							
P. armeniaca	0	0							
P. insititia			0						
P. serotina B	0	0	0						

[a] See footnote a, Table II.
[b–f] See footnotes b to f, Table I.
[g] See footnote g, Table II.
[h] Failure probably due to some local defect in manipulation of inoculation

DISCUSSION OF TABLE VI

Either a moderate or an abundant infection (Pl. 57) resulted from all inoculations except the first and second of series 103 and the third of series 110. The sparseness of infection in series 103 was probably due to a diminution of the pathogenicity of the fungus in culture, as both of the tests were made with inocula from a strain which had been in culture for more than 20 months. The reasons for the low degree of infection from the last inoculation of series 110 are not understood. It is possible again that the high temperatures of this period may have been inhibitory. *P. domestica* (see footnote h), *P. insititia*, and *P. americana* were consistently infected. *P. mahaleb* was sparsely infected, but not consistently. *P. salicina* and *P. munsoniana*, in one case each, developed infection after prolonged incubation in the greenhouse. Similarly, in two cases, *A. persica* developed sparse infection. The single test with *P. besseyi* yielded positive results after prolonged incubation. No other infection was observed. Sometimes spots or flecks developed on *P. padus*, *P. salicina*, and *P. munsoniana*.

TABLE VII.—*Summary of inoculation experiments with Coccomyces spp. from Prunus virginiana, Madison, Wis., 1917*

INOCULATIONS [a]

Location and series.	Date.	Inoculum.				Germination. [b]		
		Spores.	Source.	Age of strain in culture.	Method of application.	After hours.	Per cent.	Vigor.
Out of doors:				*Months.*				
1C	June 8	Ascospores	Leaves, Madison		Dehiscence			
4	July 21	Conidia	*P. virginiana* leaves, series 113 and 117.		Spray	48	− 1	−
4	Aug. 14	do	9-day-old culture	1.6	do	24	0	
13	Aug. 2	do	*P. virginiana* leaves, series 117 and 119.		do	24	− 1	−
13	Aug. 21	do	12-day-old culture	2.6	do			
In greenhouse:								
111	June 8	Ascospores	Leaves, Sturgeon Bay.		Dehiscence	48	95	+
111	July 13	Conidia	13-day-old culture	1.3	Spray	18	5	+
111	July 28	do	*P. virginiana* fruit, Two Rivers, Wis.		do	24	− 1	−
113	June 26	do	21-day-old culture	.7	do	24	0	
113	July 10	do	*P. virginiana* leaves, series 113.		do	48	25	+
117	July 2	do	15-day-old culture	.9	do	48	− 1	−
117	July 23	do	8-day-old culture	1.6	do			
119	July 10	do	10-day-old culture	1.2	do	48	0	
119	July 23	do	8-day-old culture	1.6	do	24	− 1	−
121	July 31	do	*P. virginiana* leaves, series 108. [f]		do	17	50	+

[a] See footnote a, Table II.
[b] See footnote b, Table I.
[f] See Table VIII.

TABLE VII.—*Summary of inoculation experiments with Coccomyces spp. from Prunus virginiana, Madison, Wis., 1917*—Continued

RESULTS

Plant and treatment.	Infection. [c], [g]														
	Out of doors.					In greenhouse.									
	Series 1C.	Series 4, from inoculation of—		Series 13, from inoculation of—		Series 111, from inoculation of—			Series 113, from inoculation of—		Series 117, from inoculation of—		Series 119, from inoculation of—		Series 121.
		July 21.	Aug. 14.	Aug. 2.	Aug. 21.	June 8.	July 13.	July 28.	June 26.	July 10.	July 2.	July 23.	July 10.	July 23.	
Inoculated:															
P. cerasus	....	0	0	0	0	0	[e](?)	0	0	0	0	0	0	0	....
P. mahaleb	....	....	....	....	*f*1	2	1	0	*f*2	*f*2	0	*f*1	1	2	[e]0
P. pennsylvanica	0	0	0	0	0	....	....	....	....	....	0	[e]0	....	....	....
P. serotina A	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....
P. serotina B	....	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. padus	....	*h*3	*h*3	*h*3	*h*3	....	....	....	....	....	....	....	....	....	....
P. virginiana	5	2	3	*h*4	*h*4	....	....	2	5	5	2	5	1	5	4
P. domestica	....	0	0	0	*f*2	4	*f*2	0	*f*3	*f*3	....	....	*f*2	*f*4	....
P. insititia	....	0	0	....	*f*2	1	1	0	....	....	....	....	*f*1	*f*3	....
P. americana A	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....
P. americana B	....	0	0	0	0	0	0	0	....	....	....	....	....	....	....
P. salicina	....	0	0	....	....	....	....	....	....	....	....	....	....	....	....
P. munsoniana	....	0	0	0	0	0	0	0	....	....	....	....	....	....	....
A. persica	....	0	0	0	0	....	....	....	....	....	....	....	0	0	....
P. armeniaca	....	0	0	....	....	....	....	....	....	....	....	....	....	....	....
P. besseyi	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....
P. mahaleb (*P. cerasus* stock)	....	....	....	....	....	....	....	....	*f*3	*f*2	....	....	....	....	....
Not inoculated:															
P. virginiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	....
P. domestica	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....
P. americana B	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....
P. serotina	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....
A. persica	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....
P. cerasus	....	....	....	0	0	....	....	....	....	....	....	....	....	....	....
P. armeniaca	....	....	....	0	0	....	....	....	....	....	....	....	....	....	....
P. mahaleb	....	....	....	0	0	....	....	....	....	....	....	....	....	....	....
P. pennsylvanica	0	....	....	....	....	....	....	....	....	....	....	....	....	....	....

[c], [e], *f* See footnotes c, e, f, Table I.
[g] See footnote g, Table II.
h Secondary infection was very abundant.
[i] See discussion, p. 561.

DISCUSSION OF TABLE VII

Either moderate or abundant infection resulted from all inoculations except the second and third of series 111, the first of series 117, and the first of series 119. In all these cases the sparseness of infection was probably attributable to unsatisfactory inocula. It will be noted that all the inocula were obtained from cultures. Of all the strains of fungi used in these inoculation experiments, those from *P. virginiana* were by far the most difficult to induce to sporulate satisfactorily in culture. Thus, in certain cases the inocula were unsatisfactory because of sparseness of spores. It will also be observed that the inocula of Table VII usually germinated less vigorously than did those of the other tables. Negative germination results in the laboratory tests,

however, do not necessarily prove that inocula are ineffective, as is attested by the results of the second inoculation of series 4.

P. virginiana (Pl. 59, E), *P. padus*, and *P. mahaleb* (except in series 121) were consistently infected. *P. mahaleb*, however, was uniformly less severely diseased than the other species named. *P. domestica* and *P. insititia* were frequently infected, usually after prolonged incubation. On August 3 several leaves of *P. cerasus* of series 111 bore scattered brown spots on which occurred numerous aggregated acervuli of a species of Cylindrosporium. It is uncertain whether this was the result of chance infection or of delayed infection. The fact that no infection occurred on the extensive control system makes the possibility of chance infection remote. However, the fact that 10 other inoculations of *P. cerasus* with strains from *P. virginiana* gave uniformly negative results is a strong argument against fully accepting this result as positive. Furthermore, the fungus when isolated possessed the cultural characters typical of strains from *P. cerasus*, which were very different from those from *P. virginiana*. Further experiments will be necessary before conclusions regarding this cross are justifiable. Meanwhile this apparently aberrant result is not included in the summary (Table IX). No other infection was observed.

TABLE VIII.—*Summary of inoculation experiments with Coccomyces spp. from Prunus serotina, Madison, Wis., 1917*

INOCULATIONS [a]

Location and series.	Date.	Inoculum.				Germination. [b]		
		Spores.	Source.	Age of strain in culture.	Method of application.	After hours.	Per cent.	Vigor.
Out of doors:				*Months.*				
1D	June 8	Ascospores	Leaves, Madison		Dehiscence			
3	July 19	Conidia	9-day-old culture	1.7	Spray	24	80	−
3	Aug. 13	do	do	2.5	do	17	− 1	−
9	July 27	do	*P. serotina* leaves, series 105.		do	24	60	+
9	Sept. 1	do	13-day-old culture	3.0	do	36	5	+
19	Sept. 24	do	17-day-old culture	1.0	do	24	15	+
In greenhouse:								
105	May 18	do	8-day-old culture	8.2	do	48	− 1	−
105	June 6	Ascospores	Leaves, Madison		Dehiscence			
105	June 13	do	do		Spray [c]	48	− 1	−
105	June 29	Conidia	20-day-old culture	1.1	Spray	18	50	−
105	July 13	do	13-day-old culture	1.5	do	18	15	+
108	May 24	Ascospores	Leaves, Madison		Spray [c]			
108	June 3	do	do		Spray [d]	24	50	+
108	July 4	Conidia	21-day-old culture	1.2	Spray			
108	July 23	do	8-day-old culture	1.8	do			
112	June 19	do	6-day-old culture	1.0	do	24	2	+
112	July 4	do	21-day-old culture	1.2	do			
120	July 17	do	*P. mahaleb* leaves, series 105.		do	48	− 1	−
120	July 28	do	*P. mahaleb* leaves, series 120.		do	20	10	−

[a] See footnote a, Table II.
[b] See footnote b, Table I.
[d] See discussion, p. 563.
[c] Crushed as cocarps in sterile distilled water.

TABLE VIII.—*Summary of inoculation experiments with Coccomyces spp. from Prunus serotina, Madison, Wis., 1917*—Continued

RESULTS

Plant and treatment.	Infection. c, g																				
	Out of doors.						In greenhouse.														
	Series 1D.	Series 3 from inoculation of—		Series 9 from inoculation of—		Series 19.	Series 105 from inoculation of—					Series 108 from inoculation of—				Series 112 from inoculation of—		Series 120 from inoculation of—	
		July 19.	Aug. 13.	July 27.	Sept. 1.		May 18.	June 6.	June 13.	June 29.	July 13.	May 24.	June 3.	July 4.	July 23.	June 19.	July 4.	July 17.	July 28.
Inoculated:																			
P. cerasus	....	h(f)	0	0	0	0	0	0	0	0	0	0	0	(?)	h(f)	0	0	0	0
P. mahaleb	....	2	2	0	0	....	0	1	1	2	....	....	....	....	....	0	1	1	0
P. pennsylvanica	0	0	0	....	....	0	....	....	....	....	....	....	....	....	....	0	....	....	....
P. serotina A	....	5	5	4	3	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P serotina B	....	5	5	2	2	5	0	3	2	4	5	2	5	4	2	4	4	3	2
P. padus	....	e 0	e 0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....
P. virginiana	0	0	0	0	0	....	0	0	(?)	(?)	h(g)	0	0	(?)	h(g)	0	0	....	....
P. domestica	....	0	0	0	0	0	0	0	0	0	0	....	....	....	....	....	....	....	....
P. insititia	....	0	0	0	0	0	0	0	0	f 4	f 4	....	....	....	....	....	....	....	....
P. americana A	....	0	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....
P. americana B	....	0	0	0	0	0	0	0	0	0	0	....	....	....	....	....	....	....	....
P. salicina	....	0	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....
P. munsoniana	....	0	0	0	0	0	0	0	0	0	0	....	....	....	....	....	....	....	....
A. persica	....	0	0	0	0	0	0	0	0	0	0	....	....	....	....	....	....	....	....
P. armeniaca	....	0	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....
P. besseyi	....	0	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....
P. mahaleb (*P. cerasus* stock)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	2
Not inoculated:																			
P. serotina B	....	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. virginiana	0	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P. domestica	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P. americana B	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P. cerasus	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....	....
A. persica	....	0	0	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P. pennsylvanica	0	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
P. avium	....	0	0	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

c, e, f See footnotes c, e, f, Table I. g See footnote g, Table II. h See discussion, p. 563.

DISCUSSION OF TABLE VIII

Either moderate or abundant infection resulted from all inoculations with strains from *P. serotina*, except the first and third of series 105 and the first and fourth of series 108. The failure of the first test on series 105 was evidently due to an unsatisfactory inoculum, as is witnessed by its low germination and the age of the strain in culture (8.2 months). The sparseness of infection from the third test on series 105 and the first on series 108 is clearly due, likewise, to unsatisfactory inocula. In both of these tests the inocula were prepared by crushing fresh ascocarps in sterile distilled water, a method which was subsequently discarded as unsatisfactory. The reasons for the sparseness of infection from the last inoculation of series 108 are not understood. They may well be associated with the high temperatures which prevailed in the greenhouses at the time of this test.

Of all the experimental plants, only *P. serotina* (Pl. 58, A) was consistently and abundantly infected. *P. mahaleb* (Pl. 58, B) was usually infected, though ordinarily rather sparsely. In two instances, after prolonged incubation in the greehouse, *P. insititia* (Pl. 58, C) developed abundant infection. On July 30, eleven days after inoculation, two of of the older leaves of *P. cerasus* of series 3 each bore a small group of closely aggregated lesions, which appeared to be secondary infections from a single primary infection on each leaf. These leaves were collected, and no further infection had developed when the plant was last noted, on October 15. Although no infection developed on the elaborate control system of the outdoor experiments, the writer believes this to be a case of chance infection. It is the only case found in the outdoor series. The bed was the one nearest to the pathologium (about 35 feet away) in which all the greenhouse inoculations were made; and it seems probable that this infection resulted from wind-borne ascospores or particles of atomized spore suspensions from the pathologium. This result is, therefore, not included in Table IX.

On August 3 one leaf of *P. virginiana* of series 105 was observed to bear numerous, closely aggregated infections. On August 7 three other leaves on the same plant and one leaf of *P. virginiana* of series 108 were found to be similarly infected. Likewise on August 3 several leaves of *P. cerasus* of series 108 were observed to bear dead brown patches on which were numerous aggregated acervuli of a species of Cylindrosporium. It is uncertain whether these results were due to a chance infection or to delayed infection. The freedom of all control plants (Pl. 58, D) from infection, and the fact that in all the greenhouse series no other such questionable cases occurred, are strong arguments against accepting the theory of chance infection. Upon the other hand, the fact that 11 similar tests on *P. cerasus* and 9 on *P. virginiana* uniformly failed to induce infection makes one hesitate to conclude that this infection resulted from the inoculations. These questions can be definitely settled only by further experiments. Meanwhile these three questionable cases are not included in the summary (Table IX). No other infection was observed.

REISOLATIONS

While it was deemed neither feasible nor necessary to make reisolations from all the crosses effected, large numbers of reisolations were made from both the outdoor and the greenhouse inoculations. Especial attention was given to reisolating from difficult crosses. Although the slow growth of the fungi in culture made this work slow and laborious, no serious difficulty was experienced in making reisolations wherever the fungi fructified with fair vigor. It was important, however, to choose the best possible material from which to isolate. Each reisolated strain agreed closely in cultural characters with the strain from which the inoculation in question had been made.

TABLE IX.—*Summary of results of inoculation experiments with Coccomyces spp. from Prunus spp., Madison, Wis., 1916 and 1917* [a]

[The average degree of infection is represented by the average of the numbers representing the severity of infection from the individual inoculations which gave positive results (see footnote c, Table I). The results of series in which the maximum infection is represented by a number less than 3 and those which represent the combined infection from two or more inoculations (see footnote j, Table II) are not included].

Plant inoculated.	Results with strains from—																				
	P. cerasus.			*P. avium.*			*P. mahaleb.*			*P. pennsylvanica.*			*P. domestica.*			*P. virginiana.*			*P. serotina.*		
	Number positive. [b]	Number negative.	Average degree of infection.	Number positive. [b]	Number negative.	Average degree of infection.	Number positive. [b]	Number negative.	Average degree of infection.	Number positive. [b]	Number negative.	Average degree of infection.	Number positive. [b]	Number negative.	Average degree of infection.	Number positive. [b]	Number negative.	Average degree of infection.	Number positive. [b]	Number negative.	Average degree of infection.
P. cerasus	9	0	4.1	7	0	3.4	11	0	3.9	1	9	3.0	0	6	....	0	10	....	0	11	....
P. avium	e1	0	5.0	e1	0	4.0	4	0	4.7	e2	0	3.0	(e)	....	....	0	e2	....	(e)	....	....
P. mahaleb	12	d1	3.2	6	0	3.0	13	0	2.7	7	1	3.3	3	3	2.0	11	1	2.0	10	3	1.4
P. pennsylvanica	0	e2	....	e0	3	....	4	1	2.5	11	0	4.2	e0	2	....	0	7	....	0	5	....
P. serotina	0	11	....	0	9	....	0	16	....	0	11	....	0	10	....	0	16	....	21	0	4.0
P. padus	0	2	....	0	3	....	0	5	....	0	4	....	0	3	....	4	0	3.0	0	5	....
P. virginiana	0	9	....	0	5	....	0	8	....	0	11	....	0	5	....	14	0	4.2	0	9	....
P. domestica	0	9	....	0	5	....	0	11	....	0	10	....	8	d1	4.4	7	4	3.2	0	8	....
P. insititia	e4	3	3.5	0	6	....	e2	7	....	0	10	....	9	0	4.2	6	2	2.0	e2	6	4.0
P. americana	0	12	....	0	10	....	0	17	....	0	14	....	9	0	3.3	0	11	....	0	13	....
P. salicina	0	9	....	0	6	....	0	4	....	0	10	....	e1	3	4.0	0	3	....	0	5	....
P. munsoniana	4	2	3.3	0	6	....	e3	7	2.5	e1	8	....	e1	5	4.0	0	6	....	0	8	....
P. cerasifera	e1	0	....	....	....	....	....	....	....	e1	0	....	....	....	....	....	....	....	....	....	....
A. persica	0	6	....	0	6	....	0	11	....	0	4	....	e2	2	1.0	0	5	....	0	8	....
A. persica nectarina	0	1	....	0	1	....	0	1	....	....	....	....	....	....	....	0	1	....	....	....	....
P. armeniaca	0	e1	....	0	3	....	0	5	....	0	4	....	0	2	....	0	3	....	0	5	....
P. besseyi	1	2	4.0	1	3	4.0	1	5	3	0	4	....	1	0	....	0	5	....	0	5	....

[a] Compiled from Tables I–VIII.

[b] All inoculations in which the fungus induced lesions and fructified are listed as positive. Cases of flecking and spotting without fructification are listed as negative. Cases in which the results of successive inoculations on the same plant were indistinguishable are treated as single inoculations.

[c] The number of experiments was limited by the failure of experimental plants to take root.

[d] Inoculated by ascospores applied by natural discharge. See discussion, p. 550.

[e] Positive results were obtained from greenhouse experiments only.

DISCUSSION OF RESULTS

A perusal of Table IX, which contains a summary of the results of the experiments of 1916 and 1917 will show that in no case did the strains from any two host plants give identically the same results. The results from strains from *P. cerasus*, *P. avium*, and *P. mahaleb* differ only very slightly, however, and from the standpoint of host relationships the strains from these species may clearly be grouped together. The strains from *P. cerasus* readily and consistently infected *P. cerasus*, *P. avium*, and *P. mahaleb*, while in certain cases, and apparently with difficulty, they infected *P. insititia*, *P. munsoniana*, *P. cerasifera*, and *P. besseyi*. The strains from *P. mahaleb* induced infection on all the plants just mentioned, except *P. cerasifera*, upon which they were not tested. In addition, however, they also infected *P. pennsylvanica*. This is the only important regard in which their results differed from those of strains from *P. cerasus* and *P. avium*. It must be borne in mind, however, that, owing to the failure of experimental plants to root, the number of tests with strains from *P. cerasus* and *P. avium* on *P.*

pennsylvanica was very limited, and it is possible that further trials may yield positive results. The results from the strain from *P. avium* paralleled those from the *P. cerasus* strains, with the exception that no infection was induced on plums. It should be remembered, however, that only one strain from *P. avium* was available, and its pathogenicity appeared to have been diminished in culture.

The strains from *P. pennsylvanica* infected *P. avium*, *P. mahaleb*, and *P. pennsylvanica* abundantly, and *P. cerasus*, *P. munsoniana*, and *P. cerasifera* with difficulty. They differed in behavior from those from *P. cerasus* chiefly in their abundant infection of *P. pennsylvanica* and their sparse infection of *P. cerasus*, on which but 1 trial of 10 gave positive results. It is important to note, however, that, while only one cross from *P. pennsylvanica* to *P. cerasus* was effected, and the reverse cross has not yet been made, crosses between *P. pennsylvanica* and *P. mahaleb*, on the one hand, and *P. cerasus* and *P. mahaleb*, on the other, were readily effected. Furthermore, *P. pennsylvanica* readily infected *P. avium*, which easily cross-infects with *P. cerasus*. It appears, therefore, that while the results from strains from *P. pennsylvanica* do not accord perfectly with those from strains secured from *P. cerasus*, *P. avium*, and *P. mahaleb*, the agreement is so close that, from the standpoint of host relationships, the strains from these four species may tentatively be considered as a single group in which varying degrees of specialization have been developed. It remains, however, for further experiments to define the extent and the constancy of this specialization. Attention is called to the fact that, while the crosses just reported suggest the possibility that strains from *P. pennsylvanica* may pass readily to *P. cerasus* by way of *P. mahaleb* or *P. avium*, no experiments were made in which a given strain was carried over in this manner. Such experiments are projected. Further discussion of these problems of specialization and a consideration of the specific relationships of the various strains of Coccomyces used in these experiments are reserved for a later paper.

The results from strains taken from *P. domestica*, *P. virginiana*, and *P. serotina* are so different that, from the standpoint of host relationships, no further grouping of strains seems feasible. Strains from *P. domestica* infected *P. domestica* and *P. americana* abundantly, and *P. salicina*, *P. munsoniana*, *A. persica*, *P. besseyi*, and *P. mahaleb* with difficulty. Those from *P. virginiana* infected *P. virginiana* and *P. padus* easily and abundantly, and *P. mahaleb* consistently (except one trial), but uniformly less abundantly. They infected *P. domestica* and *P. insititia* with difficulty. The strains from *P. serotina* showed a high degree of specialization. They infected *P. serotina* uniformly and abundantly, *P. mahaleb* fairly consistently but sparsely, and *P. insititia* with difficulty.

A condensed summary of the results of all the crosses tried appears in Table X. Of all the experimental plants, *P. mahaleb* showed the widest range of susceptibility, being infected by inocula from all the host sources

tested—viz, *P. cerasus*, *P. avium*, *P. mahaleb*, *P. pennsylvanica*, *P. domestica*, *P. virginiana*, and *P. serotina*. Details regarding the relative consistency and abundance of the infection induced in these crosses are found in Table IX. *P. cerasus* and *P. avium* were infected by inocula from *P. cerasus*, *P. avium*, *P. mahaleb*, and *P. pennsylvanica*, though in the case of *P. cerasus* the cross from *P. pennsylvanica* was effected but once in 10 trials. *P. pennsylvanica* showed a narrower range of susceptibility, being infected by inocula from *P. pennsylvanica* and *P. mahaleb* only. It should be remembered, however, that this cross was tried but twice with strains from *P. cerasus* and three times with inocula from *P. avium* (see footnote d, Table X). *P. serotina* and *P. virginiana*, respectively, were infected only by their own strains. *P. padus* was infected only by strains from *P. virginiana*. The results with *P. padus* are of special interest, inasmuch as this is the host upon which Karsten [1] originally described *Cylindrosporium padi*.

TABLE X.—*Summary of results of crosses tried in inoculation experiments with Coccomyces spp. from Prunus spp., Madison, Wis., 1916 and 1917*

Plants inoculated.	Results [a] with strains from—						
	P. cerasus.	*P. avium.*	*P. mahaleb.*	*P. pennsylvanica.*	*P. domestica.*	*P. virginiana.*	*P. serotina.*
P. cerasus	+	+	+	[c] +	−	−	−
P. avium	[d] +	[d] +	+	[d] +	.....	[d] −	.....
P. mahaleb	+	+	+	+	+	+	+
P. pennsylvanica	[d] −	[d] −	+	+	[d] −	−	−
P. serotina	−	−	−	−	−	−	+
P. padus	−	−	−	−	−	+	−
P. virginiana	−	−	−	−	−	+	−
P. domestica	−	−	−	−	+	+	−
P. insititia	[b] +	−	[b] +	−	+	+	[b] +
P. americana	−	−	−	−	+	−	−
P. salicina	−	−	−	−	[b] +	−	−
P. munsoniana	+	−	[b] +	[b] +	[b] +	−	−
P. cerasifera	[b] +	.....	.....	[b] +	.....	.....	.....
A. persica	−	−	−	−	[b] +	−	−
A. persica nectarina	−	−	−	.....	.....	−	.....
P. armeniaca	−	−	−	−	−	−	−
P. besseyi	+	+	+	−	+	−	−

[a] Compiled from Table IX. A single positive result serves to list the results of a cross as positive, even though a large number of tests may have given negative results. See footnote c.
[b] Positive results were obtained only after prolonged incubation in the greenhouse.
[c] This cross was effected but once in 10 trials.
[d] The number of experiments was limited, owing to the failure of experimental plants to root.

Of the plums tested, *P. insititia* showed the widest range of susceptibility, being infected readily by strains from *P. domestica*, fairly consistently though rather sparsely by strains from *P. virginiana*, and difficultly by inocula from *P. cerasus*, *P. mahaleb*, and *P. serotina*. *P. domestica* was infected consistently and abundantly by its own strains, and more difficultly by strains from *P. virginiana*. *P. americana* and *P. salicina* were infected only by inocula from *P. domestica*, the former abundantly

[1] KARSTEN, P. A. SYMBOLAE AD MYCOLOGIAM FENNICAM. PARS XVI. *In* Meddel. Soc. Fauna et Flora Fennica, Häftet 11, p. 159. 1885.

and consistently, and the latter with difficulty. *P. munsoniana* was infected more readily by strains from *P. cerasus* than those from any other source tried. While these strains induced fairly consistent and abundant infection a prolonged incubation period always resulted, and the cross appeared to be a rather difficult one. Infection on this host was induced with still greater difficulty by strains from *P. mahaleb*, *P. pennsylvanica*, and *P. domestica*. *P. cerasifera* was tested in only two instances (where sprouts developed from Lombard stocks). Delayed infection resulted in both cases, the inocula being, respectively, from *P. cerasus* and *P. pennsylvanica*. *A. persica* was infected difficultly and only by inocula from *P. domestica*. *A. persica nectarina* and *P. armeniaca* were tested only in the experiments of 1916, and with uniformly negative results. *P. besseyi* was difficultly infected by inocula from *P. cerasus*, *P. avium*, *P. mahaleb*, and *P. domestica*. The waxy cuticle of the leaves of this species is very resistant to wetting. This fact may be in some measure accountable for the inconsistency of results from the various tests on *P. besseyi*.

While, for purposes of summarization, it was deemed advisable to omit from Tables IX and X details regarding the flecking and spotting reported in Tables I to VIII, these apparently aberrant types of infection should be given due consideration in the interpretation of the results of these experiments. Although the confirmatory histological studies necessary to justify conclusions have not yet been completed, this flecking and spotting, in conjunction with the types of delayed infection into which they merged, make it appear that various gradations of infection may occur, ranging in all likelihood from mere penetration of the germ tube to the production of typical, sporulating lesions. This condition presents many interesting problems, and appears to offer an excellent opportunity for fundamental studies of specialization of parasitism and of the intimate relations of host and parasite. It is fully realized, however, that, while more than a thousand inoculation tests have been made, these problems are little more than defined. For their material advancement much more extensive experiments will be necessary. These should include tests in which individual strains of the fungi are carried through many generations with the aim of determining, if possible, whether experimental changes in host relations induce detectable changes in parasitism. Such studies would bear upon the possibilities of variation among strains of different ancestry on a given host, and should include comparative tests of strains obtained from various sections. In this work due consideration should be given to the possibility of variations in the susceptibility of different varieties of host species and of individuals within a variety or species. Furthermore, as the greenhouse experiments have indicated, it would be of much interest and value to trace the effects of certain variable factors, particularly temperature and the vigor of the host plant, in relation to infection.

While final conclusions are not yet justifiable, the results of these experiments make it reasonably certain that under Wisconsin conditions the practical cherry grower need have no serious concern regarding infection of cultivated cherries by *Coccomyces* spp. from wild hosts, with the possible exception of *P. pennsylvanica*. So few sweet cherries are grown in the State that infection of *P. avium* from *P. pennsylvanica* is of little importance except as it relates to the possibility of infecting *P. cerasus* by way of the sweet cherry. The direct cross from *P. pennsylvanica* to *P. cerasus* was effected but once in 10 trials. It seems improbable, therefore, that such infection would be important. If *P. mahlaleb*, however, were of common occurrence within the State, it should be listed as a dangerous harborer of infectious material. In the case of the plums it is evident that the native *P. americana* may be a harborer of infectious material for cultivated species.

SUMMARY

This paper is a report of progress on more than 1,000 cross-inoculation tests with *Coccomyces* spp. from certain of the more common species of Prunus of Wisconsin.

From the standpoint of host relationships, the strains of fungi studied are tentatively grouped as follows, according to the hosts from which they were procured: (1) *P. cerasus*, *P. avium*, *P. mahaleb*, and *P. pennsylvanica*, (2) *P. domestica*, (3) *P. virginiana*, and (4) *P. serotina*. It is realized that minor variations in pathogenicity occur among strains within these groups.

The plants inoculated varied widely both in the range and the degree of their susceptibility to inocula from the various sources. *P. mahaleb* was notable for its wide range of susceptibility, being infected in varying degrees by inocula from all the host sources tested. Among the plums, *P. insititia* was notably susceptible, while the results of the two incidental inoculations of *P. cerasifera* suggest that it has likewise a wide range of susceptibility. *P. serotina* and *P. virginiana*, on the other hand, were notable for their resistance to cross infection, while *P. padus*, the host upon which Karsten[1] originally described *Cylindrosporium padi*, was infected only by strains from *P. virginiana*. *P. salicina*, *A. persica*, *P. armeniaca* and *A. persica nectarina* were notable for their resistance to all the strains tested.

While results are listed as positive only in cases where fructifying lesions were induced (p. 544), flecking and spotting without fungal fructification frequently resulted from inoculations on uncongenial hosts. It is tentatively assumed that such manifestations represent aberrant infection, all gradations of which probably occur.

[1] KARSTEN, P. A. LOC. CIT.

The variations of results in difficult crosses with conditions not yet fully understood make it unwise to place too strong reliance upon negative results.

It is apparent from these tests, though not fully conclusive, that in Wisconsin no serious infection of cultivated cherries is induced by inocula from wild hosts, with the possible exception of *P. pennsylvanica*. It is evident, however, that the native *P. americana* may act as a harborer of infectious material for cultivated plums.

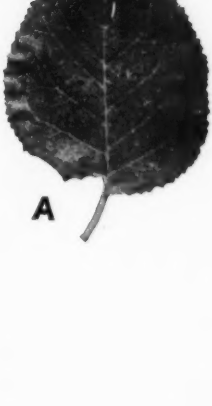
This work has defined rather than solved, certain fundamental problems regarding host relationships and specialization of parasitism within the group of fungi under investigation.

PLATE 55

Prunus leaves from inoculation experiments, illustrating various degrees of infection, as recorded in Tables I to IX:

A.—*P. mahaleb*, infected by a strain of Coccomyces from *P. serotina*.
B.—*P. serotina*, infected by a strain from *P. serotina*.
C.—*P. cerasus*, infected by a strain from *P. avium*.
D.—*P. pennsylvanica*, infected by a strain from *P. pennsylvanica*.

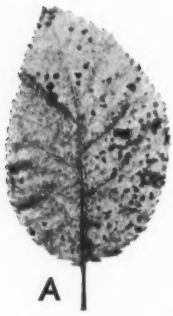
Figures A, B, C, and D would be represented in the tables by the numbers 2, 3, 4, and 5, respectively. B approaches the maximum of 3, while C approaches the minimum of 4 (see footnote c, Table I).


A

B

C

D


A

B

C

D

E

PLATE 56

Prunus leaves from inoculation series 104 (Table II), infected by strains of Coccomyces from *P. cerasus:*

A.—*P. cerasifera*, infected after prolonged incubation in the greenhouse.

B.—*P. insititia*, infected after prolonged incubation in the greenhouse.

C.—*P. mahaleb*.

D.—*P. munsoniana*, inoculated with naturally discharged ascospores on June 2; photographed on July 19. The infection appeared after prolonged incubation in the greenhouse.

E.—*P. domestica*. Spots developed after prolonged incubation in the greenhouse, but the fungus failed to fructify.

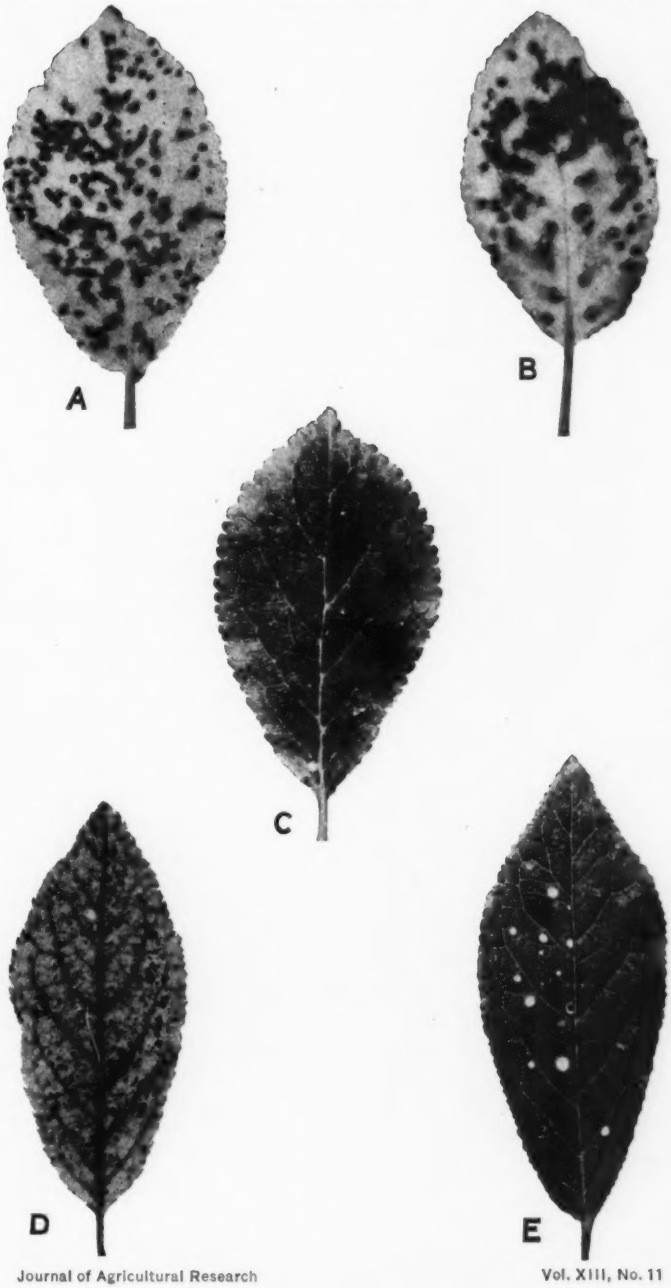
56113°—18——4

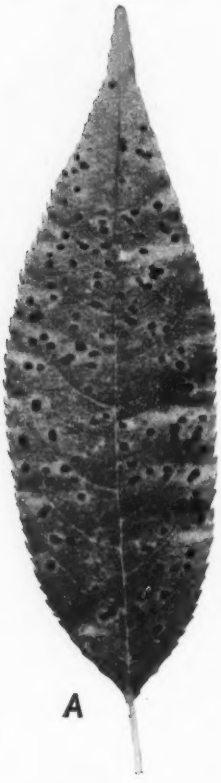
PLATE 57

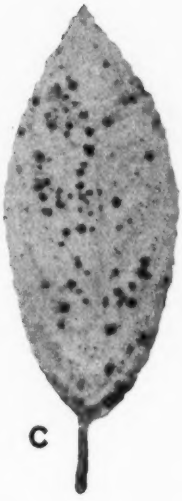
Plum leaves from inoculation series 103 (Table VI):

A.—*P. domestica.*
B.—*P. insititia.*
C.—*P. domestica,* uninoculated.
D.—*P. americana.*
E.—*P. salicina.*

These leaves were inoculated comparatively with a strain of Coccomyces from *P. domestica.*


A
B
C
D
E


A


C

B

D

PLATE 58

Prunus leaves from inoculation experiments (Table VIII):

A.—*P. serotina*, infected by a strain of Coccomyces from *P. serotina*, series 3.
B.—*P. mahaleb*, sparsely infected by a strain from *P. serotina*, series 3.
C.—*P. insititia*, infected, after prolonged incubation in the greenhouse, by a strain from *P. serotina*, series 105.
D.—*P. serotina*, uninoculated, series 105.

PLATE 59

Prunus leaves from inoculation experiments:

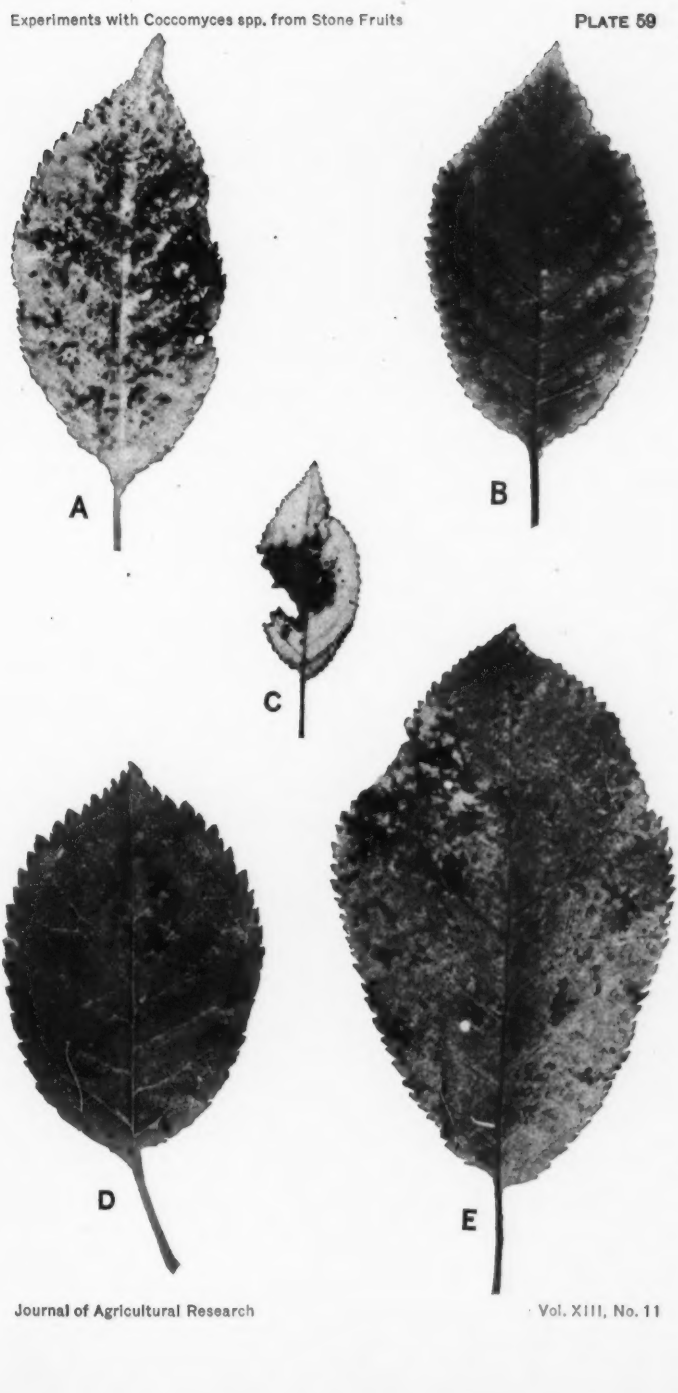
A.—*P. cerasus*, infected by a strain from *P. cerasus*, series 10 (Table II).

B.—*P. cerasus*, uninoculated, series 10.

C.—*P. pennsylvanica*, infected by naturally discharged ascospores from a leaf of *P. pennsylvanica*, series 1B (Table V).

D.—*P. cerasus*, infected by naturally discharged ascospores from a leaf of *P. cerasus*, series 101 (Table II).

E.—*P. virginiana*, infected by a strain from *P. virginiana*, series 13 (Table VII).


A
B
C
D
E

NYSIUS ERICAE, THE FALSE CHINCH BUG

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INTRODUCTION

The false chinch bug, *Nysius ericae* Schilling (*angustatus* Uhler), has been recognized for many years as a serious pest, especially in the semi-arid regions of the United States, where it causes great damage to sugar beets and cruciferous garden crops, settling upon them suddenly in enormous numbers and sucking so much sap from them that the plants wilt beyond recovery in one or two days.

When the writer was first stationed at Garden City, Kansas, in March, 1913, he could get no information regarding the life history and habits of the insect on which to base control measures. Work was therefore begun to determine these points, and the following account is prepared from data collected during that and the three following years.[1] The closest field study of the insect was made during 1913 and 1914, and the rearing work was done during 1914 and 1916.

DESCRIPTION

THE ADULT

The female is about 4 mm. long by 1.5 mm. wide. The greatest width is through the posterior edge of the prothorax and base of the wings. From this point the body tapers rapidly forward with a slight curve. The eyes project prominently on the sides at the posterior margin of the head, and the antennæ arise between the eyes and the base of the beak. The abdomen is elongate, its sides almost parallel and its apex rounded. It is entirely covered by clear membranous wings which project a little at the anal extremity. The ovipositor arises on the ventral surface of the tip of the abdomen, and is carried folded in a groove below the posterior abdominal segments, the basal portion extending forward and the distal backward just beneath.

The males are perceptibly smaller than the females, or about half the length and half the width of a grain of wheat. Their form is similar to that of the female, excepting the tip of the abdomen, which is more pointed and without the groove on the venter.

The newly matured adult is dull whitish, but in a short time this changes to dirty gray with dark or black spots. Old adults (Pl. 60) are nearly black, except the ventral portions of the posterior abdominal segments of the female, which are gray or light brown. The wings remain transparent. The antennæ are uniform brownish, the legs and tarsi light brown with black spots, and the claws black.

[1] During the summers of 1914, 1915, and 1916 the writer was assisted by Mr. F. M. Wadley. Besides rendering assistance on the entire project, he alone collected the data for the topics, "Rate of oviposition at various hours of the day" and "Seasonal variation in oviposition."

Schilling's original description, in Beiträge zur Entomologie, p. 86–87, Breslau, 1829, has been translated by Messrs. C. H. Popenoe and Gerson Garb as follows:

Heterogaster ericae. Grayish yellow; thoracic line transverse, hemelytra with discoidal punctures and posterior margin black. Membrane with smoky spots.

Lyg. thymi Fallen. Var. *a.*—Body smaller than in preceding; shape less narrow, lgt. 1¾ in., lt. ½ in. Head with black spots, median stripe pallescent. Antennæ dark, lighter at joints; thorax bears at the apex a line of black spots interrupted at the middle. The elytra cover the sides and apex of the abdomen; veins of hemelytra sprinkled with black punctures; membrane with indistinct smoky spots. Scutellum as in *thymi*. Abdomen beneath sprinkled with black, posteriorly with pale spots. Habitat on *Erica vulgaris* and allied plants.

THE EGG

FIG. 1.—*Nysius ericae:* Eggs, highly magnified.

The egg (fig. 1) is about 1.5 mm. long and 0.4 mm. wide, and tapers toward each end, one side being curved and the other nearly straight. It is of a translucent pinkish white color.

THE NYMPH

The body of the newly hatched nymph (Pl. 61, A) is about 0.7 mm. long by 0.3 mm. wide, and oval or pear-shaped, being widest behind the middle of the abdomen. Its color is translucent pinkish white, which on high magnification is seen to be due to irregular brownish opaque areas on an almost transparent background. The eyes are black and the segments of the antennæ shade almost to a flesh color at the distal ends. The dorsal portions of the fourth and fifth abdominal segments contain a large red mass which becomes indistinct after the first molt.

The nymphs become darker with age, but appear fresh and bright after each molt. After the first one (Pl. 61, B–E) there are dark areas on the sides of the thorax and anterior abdominal segments where the wing pads develop. These areas enlarge during the later instars and, with other sections of the body wall, become almost black.

The fifth instar (Pl. 61, E) is the pupa period. In it the insect is pear-shaped, and displays as much activity as is exhibited during earlier nymphal life.

LIFE HISTORY

OVIPOSITION

WHERE EGGS ARE PLACED.—The eggs are deposited in loose soil; among clods or rubbish; in composite flowers like the great-flowered gaillardia (*Gaillardia pulchella* Foug.); between the glumes in grasses like stink-grass or strong-scented love-grass (*Eragrostis major* Host.); and among the clustered parts of plants such as thyme-leaved spurge (*Chamaesyce serpyllifolia* Pers.), and carpet-weed (*Mollugo verticillata* L.); among the down from cottonwood (*Populus* spp.) wherever this down lodges in quantities; and in other similar places.

MANNER OF OVIPOSITION.—For egg-laying the female elevates the abdomen, straightens the ovipositor, and thrusts it almost vertically downward into the substance or among the parts chosen to receive the

eggs. Usually several trials are made before the female is satisfied and deposits the eggs, and sometimes the attempt is discontinued, to be resumed shortly afterwards.

Females have been observed to remain occupied at oviposition for as long as 9½ minutes, and as many as eight eggs have been found where a single female has been at work.

INCUBATION

Early in the incubation period a red spot appears near one end of the egg and at about the middle of the period two spots appear near the other end. The egg remains a translucent pink, and with proper magnification the developing nymph is plainly visible through the transparent shell.

NYMPHAL INSTARS

In conducting these experiments, after many unsuccessful attempts to rear the nymphs by ordinary laboratory methods, the newly-hatched nymphs were placed singly in bags of thin muslin or India linen which were slipped over the tips of growing plants and tied securely. This method proved more nearly successful than any other which was tried, though the handling necessary during examinations resulted in considerable loss through accidental injury to the nymphs or to their escape. At Garden City, Kans., in 1914, five individuals were held under close observation from hatching until death. At Wichita, Kans., in 1916, three individuals, one of which was kept until its death, were reared to maturity from eggs of known oviposition. The number which reached maturity, however, represents only about ½ of 1 per cent of the individuals used in the rearing experiments.

NUMBER AND LENGTH OF INSTARS

In Table I are given the number and length of instars obtained from five nymphs reared at Garden City in 1914.

TABLE I.—*Number and length of nymphal instars of Nysius ericae, Garden City, Kans., 1914*

Specimen No.	Number of days in each instar.						Length of nymphal life.	Sex.
	First.	Second.	Third.	Fourth.	Fifth.	Sixth.		
							Days.	
1	4	3	3	2	10	0	22	Male.
4	4	2	4	3	5	0	18	Do.
29	2	4	2	4	2	5	19	Female.
33	5	4	4	4	4	0	21	Male.
35	2	3	4	3	5	0	17	Do.

The only female reaching maturity (No. 29 in Table I) passed through six molts, aside from which nothing unusual was observed about her life cycle. There is slight chance for error, as the exuviæ in all cases were examined with a powerful magnifier.

Data were secured from other nymphs which remained under observation for only a portion of their life cycle, and during this period the average length of each instar was computed from these data on the basis of a much larger number. This is done in Table II which gives the average length of instars for the false chinch bug at Garden City.

TABLE II.—*Average length of nymphal instars of Nysius ericae, Garden City, Kans., 1914*

Instar.	First.	Second.	Third.	Fourth.	Fifth.
Number of nymphs	21	12	10	9	7
Days in instar (average)	4	3.75	3.2	3.1	6.3

Thus calculated, the length of the nymphal period is 20.35 days.

Data on the number and length of instars which were secured at Wichita during the rearing work of 1916 are presented in Table III.

TABLE III.—*Number and length of nymphal instars of Nysius ericae, Wichita, Kans., 1916*

Specimen No.	Number of days in each instar.					Sex.	Length of nymphal life.
	First.	Second.	Third.	Fourth.	Fifth.		
76	6	3	3	1	5	Female	18
149	7	7	3	5	15	Male	37
250	9	5	3	6	5	...do	28

Other data secured during 1916 permit averages to be presented for each instar with numbers as in Table IV, which gives the average length of instars for the false chinch bug at Wichita.

TABLE IV.—*Average length of nymphal instars of Nysius ericae, Wichita, Kans., 1916*

Instar.	First.	Second.	Third.	Fourth.	Fifth.
Number of nymphs	54	25	13	6	6
Days in instar (average)	5	3.76	3.6	4.5	3.83

This gives the length of the nymphal period as 20.69 days.

Tables I and III indicate great variation in the duration of the instars, both actually and relatively in proportion to the length of the entire nymphal period. The record of No. 29 in Table I indi-

cates a possible variation, also, in the number of instars. Further evidence of such variation was secured during 1916 from some males that apparently matured in 4 molts. Apparently 5 molts is normal; but the variation in the actual as well as the relative length of instars leads the writer to believe that a greater or a less number is not only possible but probable.

Only a portion of the process of molting has been observed—the completion of a transformation from pupa to adult. The pupa had assumed a position head downward on the underside of a leaf which was inclined at an angle of about 15°. The legs were extended well apart, and the old exuvium was holding securely. When discovered, the adult was about half disclosed, escaping through a longitudinal slit in the dorsal median line of the pupal skin. It wriggled out until only the tips of the wings and of the third pair of legs were holding, then rested two or three minutes. When activity was resumed, the legs were repeatedly touched to the leaf. To obtain a better view, the writer then attempted to move the potted plant, upon which the insect hastily secured a footing on the leaf and turned around beside the cast skin, moving with quick nervous starts, and assumed an attitude of alert expectancy, waving its antennæ excitedly. The wings were crumpled and folded, but quickly assumed the shape and position normally found in the adult.

Adult coloration developed in less than two hours.

LENGTH OF ADULT LIFE

The males reared in 1914 were held without mating until death. They lived, respectively, 33, 8, 11, and 18 days. The female was mated, producing 8 eggs and living 6 days. This gives an average adult life of 15.2 days. In 1916 only one reared adult, a male, was confined until death. It was kept unmated and lived 39 days after maturity.

Thirteen females, collected in 1913 and confined with males for eggs, lived an average of 12 days, ranging from 9 to 19. Ten collected males that were mated gave an average also of 12, varying from 9 to 18.

LENGTH OF LIFE CYCLE

At Garden City, during 1914, the average temperature being 79.78° F., the different stages from deposition of the egg to death of the resulting individual were determined as follows:

	Days.
Egg stage	4
Nymphal stage	20.35
Maturity to mating	3
Mating to oviposition	1
Beginning oviposition to death	12
Total	40.35

The period from beginning of oviposition to death, to which reference is made on page 575 under "Length of adult life," is the average of the 23 collected individuals. To give an average for the period, an insufficient number of specimens were reared and kept under observation after being mated.

REPRODUCTIVE HABITS

Newly matured females have never been observed to mate in less than three days. Eggs are not secured until one day later. Subsequent mating is frequent and promiscuous, though a female often rejects a male.

A study was made of the reproductive activities for one day, of the rate of oviposition at various hours of the day, and of the seasonal variation in oviposition.

Five pairs of *Nysius ericae* were collected and each pair was confined in a cotton-stoppered vial. They were watched continuously for eight hours, remaining in the vials during the succeeding night. Table V is a typical record. Observations began at 7.45 a. m.[1]

TABLE V.—*Twenty-four-hour record of the reproductive activities of Nysius ericae, pair 3*

Paired 9.43.	Paired 11.57.	Paired 1.15.
Parted 9.46.	Parted 11.59½.	Parted 1.17½.
Paired 10.21.	Oviposited 12.45 to 12.59 (4 eggs).	Paired 1.27.
Parted 10.25.	Paired 1.02.	Parted 1.29.
Paired 10.56½.	Parted 1.07.	Paired 1.33.
Parted 11.01.	Paired 1.09½.	Parted 1.35.
Oviposited 11.22 to 11.24½ (8 eggs).	Parted 1.10.	Paired 3.35.
		Parted 3.37.

When examined the next morning at 7.45, both insects were living, but no more eggs had been deposited.

To ascertain the rate of oviposition at various hours of the day, several pairs were confined and the eggs removed daily at 8 a. m., 1 p. m., and 5 p. m. The experiment continued from June 6 to August 5, the pairs being replaced as they died, and by the latter date a total of 463 eggs had been secured. Of this number 239 were secured at 8 a. m., 145 at 1 p. m., and 79 at 5 p. m., or in about the ratio of 3 : 2 : 1. As nearly as can be determined, feeding and reproductive activity cease during darkness. This indicates that as many eggs are deposited during the late evening and early morning as are deposited from 8 a. m. to 5 p. m., and that twice as many eggs are deposited from 8 a. m. to 1 p. m. as from 1 p. m. to 5 p. m.

This decrease in reproductive activity during the afternoon has been observed under field conditions, the insects feeding less and seeking shade through the hot part of the afternoon.

[1] References to clock time refer to standard time.

To secure data on the seasonal variation in oviposition, females were collected and confined with males, and a record kept of the egg production and of the length of life of each female. The experiment was begun on May 6 and continued until September 18. Fifty-four females collected during May deposited 260 eggs in 295 days of life; 48 females collected during June deposited 231 eggs in 166 days of life; 39 females collected during July deposited 28 eggs in 216 days of life; 10 females collected during August deposited 17 eggs in 55 days of life, and 21 females collected during September deposited 113 eggs in 119 days of life. This is at the rate during May of 1 egg per female in 1.13 days; during June, 1 egg per female in 0.718 days; during July, 1 egg per female in 7.86 days; during August, 1 egg per female in 3.235 days; and during September, 1 egg per female in 1.05 days.

These figures coincide with the reproductive activity of the species as observed in the field. During May and June and again during September and October the females mate and oviposit frequently. Beginning in July and continuing into August they are much less prolific, it being sometimes difficult to secure sufficient eggs for rearing experiments. This decreased activity is exhibited only by the adults, there being no lengthening of the incubation period or nymphal instars.

EFFECT OF TEMPERATURE ON DEVELOPMENT

With an average temperature of 79.78° F. at Garden City, Kans., eggs hatched in about 4 days, and the average nymphal period (calculated from the averages of the largest number available in each instar) is 20.35 days. The average time, therefore, from oviposition to maturity is 24.35 days.

With an average temperature of 74.75° at Wichita, eggs hatched in 3.5 days, and the average nymphal period was 20.69 days. This gives the time from oviposition to maturity as 24.19 days.

Of 6 eggs deposited October 16 and 17, 1914, two hatched November 25, one November 28, and one November 30, making the shortest possible incubation period 39 days and the longest 44 days. Twenty-six times during this period the temperature was below 32° F., the minimum being 18° and the average 49.8°. This shows an average difference of 1.16 days in the length of the incubation period for each degree of difference in average temperatures.

From the data in the preceding paragraphs it appears that development at a temperature of 74.75° requires only 0.34 of a day longer than development at a temperature of 79.78°, but at 79.78° incubation requires only 4 days, while at a temperature of 49.8° 39 days are required, or $1\frac{1}{8}$ days for each degree of difference in temperature.

Of the 6 eggs under observation at a temperature of 18° four survived, and it is not certain that the other two were killed by the cold.

NUMBER OF GENERATIONS ANNUALLY

From the data on "Length of life cycle," p. 575, the time from oviposition by one generation to oviposition by the next succeeding generation is found to be 28.35 days, the temperature being 79.78° F. In some individuals this time is shortened in the nymphal period alone by at least two days.

These figures indicate that during the period in which they were collected a generation might become mature in less than one month. During the preceding April and May the temperatures averaged respectively 53.48° and 61.9°, and during the succeeding October 58.27°. These temperatures were above the average of 49.8° at which incubation proceeded late in October and during November of the same year.

Observations of 1913 showed that five generations matured after June 1. Hibernating nymphs from 1913 or overwintered eggs that hatched early in 1914 gave rise to a generation that completed development during the last two weeks of April and oviposited early in May. As the species was not reared continuously throughout the year the number of generations annually must be deduced from the data given.

The writer regards it as conclusive that five generations of the false chinch bug matured at Garden City, Kans., during 1913 after June 1. It is safe to regard this number as the minimum for seasons of the same length. The species hibernates either as an egg or as a young nymph which completes development very early the next spring. At Garden City the overwintering forms matured during April and deposited their eggs early in May. In seasons having temperatures above the average at Garden City the generation hatching from these eggs would become nearly mature by June.

To summarize: To the minimum of five generations, an overwintering generation and a possible generation in the spring may be added, making seven in all. In seasons in which the average temperature falls below that under which these studies were pursued the number of generations will be less, and with higher average temperatures may become greater.

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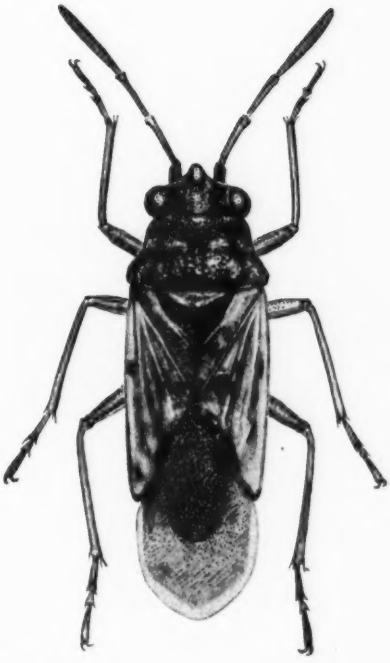
PLATE 60

Nysius ericae: Adult. ×24

Nysius ericae

PLATE 60



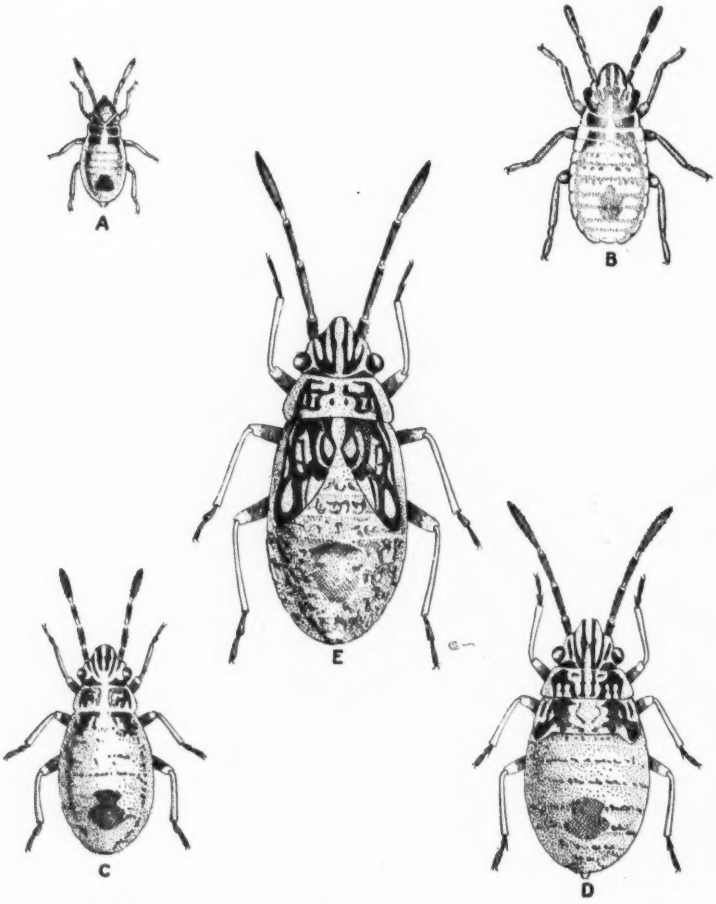

A
B
E
C
D

PLATE 61

Nysius ericae: Nymphal instars, greatly enlarged

A.—First-instar nymph.
B.—Second-instar nymph.
C.—Third-instar nymph.
D.—Fourth-instar nymph.
E.—Fifth-instar nymph, or pupa.

COMPARATIVE TRANSPIRATION OF CORN AND THE SORGHUMS

By EDWIN C. MILLER, *Associate Plant Physiologist, Department of Botany, Kansas Agricultural Experiment Station*, and W. B. COFFMAN, *Graduate Student, Kansas Agricultural College*

INTRODUCTION

In connection with the investigations of the water relations of corn. (*Zea mays*) and the sorghums (*Andropogon sorghum*) previously reported by the senior writer,[1] it was thought advisable to study the daily transpiration of these plants. A knowledge of the rate of transpiration of these plants under the same environment is essential in order to determine the factors that are concerned in their relative ability to withstand severe climatic conditions. A study of the rate of transpiration at various stages of the development of these plants should help to determine whether the ability of the sorghums to withstand severe climatic conditions better than the corn plant is aided by the power of the sorghums to retard the rate of water loss from their leaves or by the fact that they have a much smaller leaf surface exposed for the evaporation of water The experiments herein reported were conducted during the summers of 1916 and 1917 at the State Branch Experiment Station at Garden City, Kans.

EXPERIMENTAL METHODS

CULTURAL METHODS

The plants used in these experiments in 1916 were Pride of Saline corn, Dwarf Blackhull kafir, Dwarf milo, and Blackhull kafir. In 1917 in addition to these, Sherrod's White Dent corn, Freed's White Dent corn, Red Amber sorgo, Freed's sorgo, and feterita were used. These plants were grown in large galvanized-iron cans. The cans were 24 inches in height, with a diameter of 15 inches, and under the conditions of these experiments contained about 120 kilos of soil. The soil was worked through a ¼-inch mesh screen and was thoroughly tamped in the cans. The soil used in 1916 had a moisture content of 18 per cent and a wilting coefficient of 11.1, while the moisture content of the soil used in 1917 was 22 per cent and had a wilting coefficient of 15.1. Thus, for both seasons there was a difference of approximately 7 per cent between the water

[1] MILLER, E. C. COMPARATIVE STUDY OF THE ROOT SYSTEMS AND LEAF AREAS OF CORN AND THE SORGHUMS. *In* Jour. Agr. Research, v. 6, no. 9, p. 311–332, 3 fig. pl. 38–44. 1916. Literature cited, p. 331.
——— RELATIVE WATER REQUIREMENT OF CORN AND THE SORGHUMS. *In* Jour. Agr. Research, v. 6, no. 13, p. 473–484, 1 fig., pl. 70–72. 1916.
——— DAILY VARIATION OF WATER AND DRY MATTER IN THE LEAVES OF CORN AND THE SORGHUMS. *In* Jour. Agr. Research, v. 10, no. 1, p. 11–45, 10 fig., pl. 3. 1917.

Journal of Agricultural Research, Washington, D. C.
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Vol. XIII, No. 11
June 10, 1918
Key No. Kans.-13

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content of the soil used and its wilting coefficient. The method of sealing the cans and watering the plants was the same as that used in the determination of the water requirement of corn and the sorghums.[1] During the period of the experiment water was added to the cans from three to four times each day, in order to keep the moisture content of the soil as nearly constant as possible.

The number of plants was reduced to one to each can for Blackhull kafir, Red Amber sorgo, and the different varieties of corn, while for Dwarf milo, feterita, Dwarf Blackhull kafir, and Freed's sorgo the number of plants varied from one to three to each can. The number of plants in each is shown in the tables that record the data of the different experiments. The plants thus grown were as large and vigorous as those growing in the field under favorable conditions (Pl. 62–63). All the leaves remained vigorous long after the plants had reached their full vegetative growth, while all the plants that were allowed to mature produced a normal yield of grain.

EVAPORATION

The evaporation was determined by means of the Livingston porous-cup atmometers, and the cups used both in 1916 and 1917 had a coefficient of 74. These atmometers were connected with burettes that were graduated to 0.1 c. c., and readings were made every two hours at the time of weighing the cans. In 1916 the atmometers were placed at a height of 2 feet in the open, while in 1917 they were placed at the same height in the center of a plot that was planted to corn. The cups were thus shaded after the corn had reached a height of 2 feet, so that the rate of evaporation as shown in the results was not so high in 1917 as in 1916.

DETERMINATION OF TRANSPIRATION

The cans were mounted on small wooden platforms provided with castors and were moved about on tracks made of unmatched boards. The cans were left in the open on the surface of the ground for the experiments in 1916, but in 1917 they were placed in a pit in the center of a plot that was planted to corn. The pit was of such a depth that the surface of the cans were on a level with the top of the ground (Pl. 62, C). This arrangement placed the plants more nearly under field conditions and reduced to a minimum the injury to the leaves on account of the prevailing high winds.

The plants were weighed on scales of the platform type that had a carrying capacity of 180 kilos and were sensitive to about 5 gm. The cans were weighed in a scale house in order to avoid any error in weight caused by the wind. The time required to bring the three or four plants used in the experiment to the scale house, weight them, and return them

[1] Miller, E. C. op. cit.

to their position in the open amounted to five or six minutes. The loss of water from the plants was determined in most of the experiments every two hours from 7 a. m. to 7 p. m. Determinations were made in two experiments in 1916 for each 2-hour period of the night, but since the loss of water from the plants during the night was very small, it was not deemed of sufficient importance to carry the night experiments further.

After an experiment had been completed the leaves and sheaths of the plants were cut in convenient lengths and the outline of these portions carefully traced on unruled paper with a hard lead pencil. The areas inclosed by these outlines were then determined by means of a polar planimeter. From the areas thus obtained the rate of transpiration per unit of leaf surface was calculated.

EXPERIMENTAL DATA

Five experiments were conducted in 1916 and eight in 1917. In the former year three varieties of plants were used in each experiment, while in 1917 four varieties were used. With the exception of two experiments in 1916, the transpiration was determined every two hours from 7 a. m. to 7 p. m. and for a period of two or three days. The results of the different experiments are shown in Tables II and III. The loss of water is expressed in grams per plant per hour, while the rate of transpiration is expressed in grams per square meter of leaf surface per hour and in grams per square meter of combined leaf and sheath surface per hour. The average hourly evaporation for each 2-hour period is also recorded. The data shown in these tables are expressed graphically in figures 1 to 13. In these figures the relative leaf surface of the plants used in each experiment is also shown. A general description of the plants used in each experiment is given in Table I.

TABLE I.—*General description of the plants used in transpiration experiments during the summers of 1916 and 1917 at Garden City, Kans.*

Date.	Plant.	Number of plants.	Height of plants.	Leaf surface per plant.	Sheath surface per plant.	General remarks.[a]
1916.			*Ft. in.*	*Sq. cm.*	*Sq. cm.*	
July 6–9	Corn, Pride of Saline	1	2 8	10,431	419	9F and 3P unfolded leaves.
	Kafir, Dwarf Blackhull	1	2 0	5,179	219	8F and 2P unfolded leaves.
	Milo, Dwarf	2	2 4	3,225	403	9 leaves. Booting.
July 10–13	Corn, Pride of Saline	1	2 10	10,701	512	9F and 4P unfolded leaves.
	Kafir, Blackhull	1	2 1	6,069	272	8F and 3P unfolded leaves.
	Milo, Dwarf	2	2 7	3,134	541	9 leaves. Booting.
July 17–18	Corn, Pride of Saline	1	4 0	13,119	836	11F and 4P unfolded leaves.
	Kafir, Dwarf Blackhull	1	2 6	6,527	448	12 leaves. Booting.
	Milo, Dwarf	2	4 6	2,728	422	9 leaves. Blooming.
	Corn, Pride of Saline	1	5 0	13,029	1,124	14 leaves. Tasseling.
July 26–27	Kafir, Blackhull	1	3 0	10,101	566	11F and 2P unfolded leaves.
	Milo, Dwarf	2	4 6	2,825	387	9 leaves. Grain in the milk.
	Corn Pride of Saline	1	6 0	10,668	1,070	15 leaves. Ears forming.
July 31–Aug. 2	Kafir, Dwarf Blackhull	3	4 0	6,186	381	11 leaves. Blooming.
	Milo, Dwarf	3	4 6	2,580	390	9 leaves. Seed in dough stage.
1917.						
	Corn, Freed's White Dent.	1	2 0	8,126	319	9 F and 4P unfolded leaves.
	Feterita	2	2 0	3,944	407	11 leaves. Booting.
July 10–12	Sorgo, Freed's	2	2 0	3,236	242	8F and 2P unfolded leaves.
	Milo, Dwarf	2	1 4	5,780	207	10 F and 3P unfolded leaves.
	Corn, Pride of Saline	1	3 4	9,664	505	8F and 4P unfolded leaves.
	Corn, Sherrod's White Dent.	1	3 4	6,264	545	8F and 4P unfolded leaves.
July 13–16	Sorgo, Freed's	3	3 6	3,154	442	10 leaves. Booting.
	Kafir, Dwarf Blackhull	2	1 4	3,965	286	8F and 3P unfolded leaves.
	Corn, Freed's White Dent.	1	3 9	11,225	662	10F and 5P unfolded leaves.
	Feterita	2	3 9	2,953	335	10 leaves. Heading.
July 17–19	Kafir, Dwarf Blackhull	2	2 9	5,255	234	9F and 2P unfolded leaves.
	Milo, Dwarf	2	2 0	6,398	333	10 leaves. Booting.
	Corn, Pride of Saline	1	3 4	12,989	518	10 F and 4P unfolded leaves.
July 20–22	Sorgo, Freed's	3	5 10	3,029	330	10 leaves. Blooming.
	Sorgo, Red Amber	1	4 0	4,001	686	10 leaves. Booting.
	Milo, Dwarf	2	3 0	7,464	437	12 leaves. Booting.
	Corn, Sherrod's White Dent.	1	4 0	10,916	840	16 leaves. Shooting.
July 23–25	Feterita	1	5 0	3,624	408	12 leaves. Blooming.
	Sorgo, Freed's	2	6 3	2,951	380	9 leaves. Blooming.
	Milo, Dwarf	2	3 3	6,330	513	11 leaves. Heading.
	Corn, Pride of Saline	1	3 8	16,943	798	12 F and 4P unfolded leaves.
July 26–27	Sorgo, Freed's	2	6 3	2,793	585	9 leaves. Blooming
	Sorgo, Red Amber	1	3 8	4,843	634	12 leaves. Heading.
	Kafir, Dwarf	2	2 6	6,710	422	11 leaves. Booting.
	Corn, Freed's White Dent.	1	4 4	15,205	997	14F and 3P unfolded leaves.
	Feterita	2	5 0	3,601	421	10 leaves. Finished blooming.
July 30–31	Sorgo, Red Amber	1	5 6	3,973	660.	10 leaves. Blooming.
	Kafir, Dwarf Blackhull	2	3 0	7,159	430	14 leaves. Booting.
	Corn, Freed's White Dent	1	6 0	14,568	1,334	16 leaves. Shooting.
	Corn, Sherrod's White Dent.	1	5 6	10,825	960	12 leaves. Grain in milk
August 2–3	Feterita	2	4 9	3,038	333	8 leaves. Seed forming.
	Sorgo, Red Amber	1	6 0	4,131	646	10 leaves. Seed forming.

[a] F=Leaves fully unfolded: P=leaves partially unfolded.

TABLE II.—*Rate of the hourly transpiration of corn and the sorgums at Garden City, Kans., in 1916*[a]

Period ending—	Evaporation per hour.	CORN, PRIDE OF SALINE (1).			KAFIR, DWARF BLACKHULL (1).			MILO, DWARF (2).		
		Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.
July 5:	*C. c.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
3 p. m.	6.4	185	175.8	169.2	57	109.1	104.7	62	191.4	167.9
5 p. m.	5.1	117	111.5	107.3	39	75.3	72.3	43	131.7	115.6
July 6:										
7 a. m.	1.1	13	12.9	12.4	4	8.1	7.8	3	10.5	9.2
9 a. m.	2.0	77	73.9	71.1	21	40.1	38.9	28	87.6	78.8
11 a. m.	3.2	107	102.4	97.7	49	95.6	91.7	44	137.2	120.3
1 p. m.	4.7	155	148.2	142.6	89	170.9	164.0	75	230.9	202.6
3 p. m.	5.5	184	175.4	168.7	81	157.4	151.0	58	180.6	158.4
5 p. m.	5.3	124	118.2	113.7	43	82.1	78.7	46	142.6	125.1
7 p. m.	3.9	63	60.5	58.2	11	20.3	19.5	11	38.3	29.2
July 7:										
7 a. m.	.8	8	7.9	7.7	4	7.9	7.6	3	8.3	7.3
9 a. m.	4.7	135	128.2	123.3	57	110.1	105.6	51	158.9	139.4
11 a. m.	6.4	205	195.4	188.0	85	163.2	156.6	87	268.1	235.2
1 p. m.	8.1	176	167.7	161.4	92	177.7	170.5	83	257.0	225.7
3 p. m.	8.6	205	195.8	188.4	103	197.9	189.9	79	246.5	216.2
5 p. m.	8.4	187	178.7	171.9	81	157.4	151.0	71	219.3	192.4
7 p. m.	5.0	74	70.5	67.9	7	13.5	13.0	18	55.0	48.3
July 8:										
7 a. m.	.8	5	4.8	4.6	5	9.2	8.8	2	7.4	6.5
9 a. m.	4.6	135	128.2	123.3	57	109.1	104.7	62	191.4	167.9
11 a. m.	6.1	213	202.5	194.9	85	164.1	157.5	79	246.5	216.2
1 p. m.	7.1	233	222.5	214.5	123	238.5	228.8	94	290.6	245.9
3 p. m.	8.1	219	208.7	200.8	110	212.4	203.8	108	334.8	293.7
5 p. m.	7.9	201	192.0	184.8	85	164.1	157.5	64	197.6	173.3
7 p. m.	6.7	109	104.4	100.4	25	47.3	45.4	25	76.7	67.3
July 9:										
7 a. m.	1.0	12	11.8	11.4	7	12.6	12.0	4	13.2	11.2
11 a. m.	6.6	195	185.4	178.4	97	187.8	180.2	90	287.9	245.5
3 p. m.	9.3	265	252.8	243.2	141	273.2	262.2	127	403.5	344.1
7 p. m.	8.3	156	148.3	142.7	60	155.4	149.2	52	166.7	142.1
July 10:										
7 a. m.	1.6	15	14.1	13.5	4	7.9	7.6	4	13.2	11.2
9 a. m.	5.2	155	145.4	138.3	103	169.7	162.4	64	203.4	173.4
11 a. m.	8.1	241	224.8	214.6	117	191.9	183.7	117	372.4	317.6
1 p. m.	10.1	293	274.4	261.8	131	215.8	206.6	138	439.4	374.7
3 p. m.	10.8	290	271.1	258.7	159	262.8	251.5	129	412.3	351.6
5 p. m.	9.9	230	215.0	205.2	120	197.7	189.2	103	327.0	278.8
7 p. m.	7.5	109	102.4	97.7	32	52.7	50.5	35	113.2	96.6
July 11:										
7 a. m.	1.5	9	8.8	8.4	5	8.8	8.4	4	13.2	11.2
9 a. m.	4.5	106	99.1	94.6	57	93.1	89.1	39	124.4	106.1
11 a. m.	6.3	145	135.6	129.4	74	121.9	116.7	71	225.7	192.4
1 p. m.	7.3	247	231.4	220.8	106	174.6	167.1	104	332.6	283.6
3 p. m.	7.4	233	218.3	208.3	127	210.0	201.0	104	332.6	283.6
5 p. m.	6.1	187	175.3	167.3	92	151.6	145.1	71	225.7	192.4
July 12:										
8 a. m.	.6	14	12.8	12.2	8	13.2	12.6	5	16.1	13.7
9 a. m.	3.7	170	158.9	151.7	35	57.7	55.2	35	113.2	96.6
11 a. m.	5.1	209	194.9	186.0	99	163.1	156.1	94	299.1	255.0
1 p. m.	6.4	219	205.2	195.8	103	169.7	162.4	95	304.6	259.8
3 p. m.	4.1	106	99.1	94.6	103	183.3	174.3	60	192.2	163.9
5 p. m.	3.5	65	63.7	57.7	43	76.0	72.3	27	84.5	72.1
7 p. m.	2.7	21	20.1	19.2	14	25.0	23.8	27	84.5	72.1
July 13:										
7 a. m.	.7	8	7.7	7.4	7	11.6	11.1	3	10.4	8.8
9 a. m.	3.7	131	141.1	133.8	75	133.2	126.7	48	152.3	129.9
11 a. m.	5.6	191	205.8	195.0	103	183.3	174.3	85	271.1	231.2
1 p. m.	5.9	212	228.4	216.5	106	189.5	180.2	97	310.2	264.5
3 p. m.	7.1	273	293.6	278.2	152	271.8	258.4	121	384.4	327.8
July 17:										
9 a. m.	5.8	213	162.0	152.3	95	146.1	136.9	73	265.3	230.0
11 a. m.	8.4	241	183.3	172.4	109	167.5	156.9	92	336.7	291.9
1 p. m.	9.3	237	180.7	169.8	159	243.3	227.8	108	395.3	342.7
3 p. m.	9.6	265	202.4	190.3	145	221.9	207.8	119	433.7	376.0
5 p. m.	8.9	255	194.4	182.7	121	184.4	172.7	94	343.1	297.5
7 p. m.	6.1	109	83.5	78.5	57	86.4	81.0	37	136.3	118.2

[a] The figures inclosed in parentheses represent the number of plants to each can.

TABLE II.—*Rate of the hourly transpiration of corn and the sorghums at Garden City, Kans., in 1916*—Continued

Period ending—	Evaporation per hour.	CORN, PRIDE OF SALINE (1).			KAFIR, DWARF BLACKHULL (1).			MILO, DWARF (2).		
		Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.
July 18:	*C. c.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
7 a. m.	1.5	23	17.5	16.5	5	7.3	6.8	9	31.1	27.0
9 a. m.	6.1	191	145.6	136.9	113	172.9	161.9	57	206.8	179.3
11 a. m.	9.0	244	186.0	174.9	135	205.8	192.7	85	310.2	268.9
1 p. m.	8.8	244	186.0	174.9	138	211.1	197.8	89	323.9	280.8
3 p. m.	8.4	255	194.0	182.4	163	249.4	233.6	106	388.0	336.3
5 p. m.	8.2	199	151.3	142.3	77	118.6	111.1	60	220.5	191.2
July 26:										
8 a. m.	3.9	121	92.5	85.1	75	73.7	69.5	35	125.5	110.4
10 a. m.	6.7	212	162.7	149.8	149	151.5	143.2	79	281.1	247.3
12 noon	8.2	291	223.0	205.3	177	180.5	170.7	99	350.1	307.9
2 p. m.	9.5	329	252.5	232.5	219	223.9	211.6	122	432.4	379.5
4 p. m.	9.5	259	198.4	182.7	213	216.7	204.9	117	412.8	363.1
6 p. m.	9.1	236	181.1	166.8	127	130.1	122.9	58	206.0	181.2
8 p. m.	6.7	164	125.9	115.9	31	34.8	32.7	27	93.7	82.4
10 p. m.	3.9	11	8.1	7.4	18	19.9	18.7	3	12.4	10.9
July 27:										
12 midnight	3.4	25	19.2	17.7	14	15.4	14.5	13	44.2	38.9
2 a. m.	1.6	25	19.2	17.7	3	4.0	3.6	5	18.6	16.3
4 a. m.	.8	18	13.8	12.7	3	4.0	3.6	2	6.2	5.4
6 a. m.	.9	31	24.2	22.3	15	16.0	15.1	5	18.6	16.3
8 a. m.	2.7	71	54.5	50.2	57	62.3	58.7	21	75.1	66.1
10 a. m.	4.9	149	114.0	104.9	92	101.5	95.5	57	206.7	176.5
July 31:										
10 a. m.	4.9	191	179.0	162.7	75	121.8	114.7	58	224.3	194.8
12 noon	6.5	237	222.1	201.9	104	167.8	158.1	75	292.8	254.3
2 p. m.	6.9	255	238.5	216.8	112	181.0	170.5	83	319.9	277.9
4 p. m.	7.3	241	225.4	204.8	94	152.5	143.6	70	270.2	234.7
6 p. m.	6.1	167	156.0	141.8	49	80.3	75.6	37	142.2	123.5
8 p. m.	2.6	29	26.7	24.3	3	5.7	5.3	8	31.7	27.5
August 1:										
8 a. m.	1.5	22	20.8	18.9	7	11.3	10.7	5	18.1	15.7
10 a. m.	6.0	202	189.3	172.0	71	114.5	107.9	57	219.1	190.3
12 noon	7.9	276	258.7	235.1	112	181.0	170.5	85	329.6	286.3
2 p. m.	9.1	305	285.8	259.3	119	192.4	181.2	97	376.1	326.2
4 p. m.	9.1	315	294.7	267.9	121	196.4	185.0	95	370.3	321.7
6 p. m.	8.1	241	225.4	204.8	89	143.1	134.8	71	274.7	238.6
8 p. m.	6.8	81	76.4	69.4	14	22.9	21.6	21	82.1	71.3
10 p. m.	4.3	31	29.5	26.8	5	7.5	7.1	2	9.0	7.9
August 2:										
12 midnight	3.3	18	16.9	15.3	3	5.7	5.3	4	14.2	12.4
2 a. m.	2.6	35	32.8	29.8	4	5.9	5.6	2	9.0	7.9
4 a. m.	2.1	15	13.6	12.3	5	7.5	7.1	7	27.1	23.6
6 a. m.	1.6	21	17.5	15.9	12	14.5	13.7	8	28.7	24.9
8 a. m.	4.4	135	126.1	114.6	41	66.5	62.7	34	132.5	115.1
10 a. m.	7.5	227	212.3	192.9	89	143.1	134.8	75	292.8	254.3
12 noon	9.7	290	271.8	246.9	114	184.8	174.1	88	343.2	298.1

TABLE III.—*Rate of hourly transpiration of corn and the sorghums at Garden City, Kans., in 1917* [a]

Period ending—	Evaporation per hour.	MILO, DWARF (2).			SORGO, FREED'S (2).			FETERITA (2).			CORN, FREED'S WHITE DENT (1).		
		Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.
July 10:	C.c.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.
9 a. m.	1.8	50	86.6	83.6	34	105.1	97.7	43	109.0	98.9	85	104.5	100.7
11 a. m.	3.4	71	122.8	118.6	55	170.0	158.0	66	167.3	151.7	89	109.5	105.5
1 p. m.	4.5	87	150.6	145.4	53	163.8	152.3	78	197.7	179.3	135	166.1	160.0
3 p. m.	5.1	87	150.6	145.4	55	170.0	158.0	80	202.8	183.9	142	174.7	168.2
5 p. m.	4.5	74	128.0	123.6	46	143.7	132.2	62	157.2	142.5	128	157.4	151.7
7 p. m.	3.9	28	48.4	46.8	16	49.5	46.0	23	58.3	52.9	50	61.5	59.2
July 11:													
7 a. m.	.8	3	5.2	5.0	3	9.3	8.6	4	10.1	9.2	6	7.4	7.1
9 a. m.	4.6	60	103.8	100.2	35	108.2	100.6	50	126.7	114.9	85	104.5	100.7
11 a. m.	7.9	84	145.4	140.4	57	176.2	163.8	74	187.5	170.1	174	214.0	206.2
1 p. m.	7.8	106	183.4	177.2	74	228.7	212.6	94	238.3	216.1	170	209.1	201.4
3 p. m.	8.0	101	174.8	168.8	64	197.8	183.9	101	256.0	232.2	184	226.3	218.0
5 p. m.	8.0	90	155.8	150.4	60	185.5	172.4	83	210.4	190.8	156	191.9	184.8
7 p. m.	5.6	35	60.6	58.4	21	64.9	60.3	34	86.2	78.2	78	95.9	92.4
July 12:													
7 a. m.	.8	1	1.8	1.6	2	6.2	5.7	4	10.1	9.2	7	8.6	8.3
9 a. m.	3.8	73	126.2	122.0	41	126.7	117.8	44	111.5	101.1	78	95.9	92.4
11 a. m.	5.5	101	174.8	168.8	64	197.8	183.9	85	215.6	195.4	159	195.6	188.4
1 p. m.	6.3	110	190.4	183.8	89	275.1	255.7	110	278.8	252.9	198	243.5	234.6
3 p. m.	7.7	122	211.0	203.8	97	299.8	278.7	115	291.5	264.4	230	282.9	272.5
5 p. m.	6.8	73	126.2	122.0	55	170.0	158.0	89	225.6	204.6	216	265.7	255.9
7 p. m.	5.5	37	64.0	61.8	35	108.2	100.6	51	129.3	117.2	99	121.8	117.3
		CORN, SHERROD'S WHITE DENT (1).			CORN, PRIDE OF SALINE (1).			KAFIR, DWARF BLACKHULL (2).			SORGO, FREED'S (3).		
July 13:													
9 a. m.	3.6	96	153.4	141.0	89	92.1	87.5	39	98.4	94.0	44	139.6	122.3
11 a. m.	7.9	135	215.7	198.2	167	172.9	164.2	60	151.3	144.6	91	288.6	253.0
1 p. m.	7.8	135	215.7	198.2	191	197.7	187.8	66	166.5	159.0	99	314.0	275.2
3 p. m.	6.3	145	231.6	212.9	163	168.7	160.3	71	179.1	171.1	99	314.0	275.2
5 p. m.	5.6	128	204.5	188.0	156	161.5	153.4	62	156.4	149.4	90	285.4	250.2
7 p. m.	4.7	71	113.4	104.3	92	95.2	90.5	27	68.1	65.1	44	139.6	122.3
July 14:													
7 a. m.	1.0	4	6.4	5.9	6	6.2	5.9	1	2.5	2.4	3	9.5	8.3
9 a. m.	5.1	71	113.4	104.3	89	92.1	87.5	39	98.4	94.0	37	117.3	102.9
11 a. m.	4.0	53	84.7	77.8	82	84.9	80.6	27	68.1	65.1	30	95.1	83.4
1 p. m.	3.5	53	84.7	77.8	71	73.5	69.8	35	88.3	84.3	34	107.8	94.5
3 p. m.	3.5	86	137.4	126.3	124	128.4	121.9	35	88.3	84.3	43	136.4	119.6
5 p. m.	3.8	86	137.4	126.3	99	102.5	97.3	43	108.5	103.6	45	142.7	125.1
7 p. m.	2.5	53	84.7	77.8	32	33.1	31.6	12	30.3	28.9	12	38.1	33.4
July 15:													
7 a. m.	.6	2	3.2	2.9	5	5.2	4.9	1	2.5	2.4	3	9.5	8.3
9 a. m.	3.6	60	95.8	88.1	92	95.2	90.5	48	121.1	115.7	40	126.8	111.2
11 a. m.	3.9	113	180.5	165.9	152	157.3	149.5	55	138.7	132.5	56	177.6	155.7
1 p. m.	4.7	117	186.9	171.8	156	161.5	153.4	62	156.4	149.4	70	222.0	194.6
3 p. m.	4.0	103	164.5	151.2	135	139.8	132.7	50	126.1	120.5	58	183.9	161.3
5 p. m.	3.2	92	147.0	135.1	99	102.5	97.3	35	88.3	84.3	43	136.4	119.6
7 p. m.	2.7	53	84.7	77.8	50	51.7	49.2	11	27.7	26.5	14	44.4	38.6

[a] The figures inclosed in parentheses represent the number of plants to each can.

TABLE III.—*Rate of hourly transpiration of corn and the sorghums at Garden City, Kans., in 1917*—Continued

Period ending—	Evaporation per hour.	MILO, DWARF (2).			KAFIR, DWARF BLACKHULL (2).			CORN, FREED'S WHITE DENT (1).			FETERITA (2).		
		Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.
July 17:	*C.c.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
9 a. m.	3.3	57	89.1	84.6	34	64.7	61.9	117	104.3	98.4	32	108.3	97.2
11 a. m.	4.4	103	160.9	153.0	64	121.8	116.6	177	157.8	148.9	64	216.6	194.5
1 p. m.	6.1	120	187.5	178.3	83	157.9	151.2	206	183.6	173.3	97	328.2	294.8
3 p. m.	6.7	118	184.4	175.3	83	157.9	151.2	191	170.2	160.6	94	318.1	285.7
5 p. m.	5.9	83	129.7	123.3	64	121.8	116.6	152	135.4	127.8	60	203.0	182.4
7 p. m.	4.9	21	32.8	31.2	14	26.6	25.5	74	66.0	62.2	21	71.1	63.7
July 18:													
7 a. m.	.7	2	3.1	3.0	2	3.8	3.6	5	4.5	4.2	2	6.8	6.1
9 a. m.	2.8	74	115.6	110.0	67	127.5	122.0	128	114.1	107.7	41	138.7	124.6
11 a. m.	4.7	94	146.9	139.7	69	131.3	125.7	184	164.0	154.8	76	257.2	231.0
1 p. m.	6.4	122	190.6	181.3	106	201.7	193.1	241	214.8	202.7	110	372.3	334.3
3 p. m.	6.2	142	221.9	211.0	117	222.6	213.1	259	230.8	217.8	103	348.7	313.2
5 p. m.	4.6	74	115.6	110.0	62	118.0	112.9	188	167.6	158.1	62	209.8	188.4
7 p. m.	3.1	12	18.7	17.8	2	3.8	3.6	18	16.0	15.1	11	37.2	33.4
July 19:													
7 a. m.	.7	2	3.1	3.0	2	3.8	3.6	2	1.8	1.7	1	3.4	3.1
9 a. m.	2.6	60	93.7	89.2	43	81.9	78.3	135	120.3	113.5	37	125.2	112.5
11 a. m.	3.7	103	160.9	153.0	94	178.9	171.2	170	151.5	143.0	64	216.6	194.5
1 p. m.	4.8	126	196.9	187.2	97	184.6	176.7	213	189.8	179.1	96	324.9	291.6
3 p. m.	4.7	108	168.7	160.4	94	178.9	171.2	195	173.8	164.0	85	287.6	258.4
5 p. m.	4.7	94	146.9	139.7	67	127.5	122.0	156	139.0	131.2	66	223.2	200.4
7 p. m.	3.9	35	54.7	52.0	28	53.2	51.0	85	75.8	71.5	45	152.3	136.8
		MILO, DWARF (2).			SORGO, RED AMBER (1)			CORN, PRIDE OF SALINE (1).			SORGO, FREED'S (3).		
July 20:													
9 a. m.	3.0	101	135.2	127.8	67	167.5	142.9	124	95.5	91.8	46	151.8	136.9
11 a. m.	3.9	140	187.5	177.2	117	292.5	249.5	181	139.3	134.0	71	234.3	211.3
1 p. m.	4.9	170	227.7	215.2	138	345.0	294.2	241	185.6	178.4	103	339.9	306.5
3 p. m.	5.3	167	223.7	211.4	138	345.0	294.2	223	171.7	165.1	106	349.8	315.5
5 p. m.	4.9	135	180.8	170.9	103	257.5	219.6	206	158.6	152.4	95	313.5	282.7
7 p. m.	4.0	30	40.2	38.0	28	70.0	59.7	71	54.7	52.6	19	62.7	56.5
July 21:													
7 a. m.	.4	1	1.3	1.2	1	2.5	2.1	2	1.5	1.4	1	3.3	3.0
9 a. m.	2.9	53	71.0	67.1	32	94.1	78.2	67	51.5	49.6	33	108.9	98.2
11 a. m.	5.1	122	163.4	154.4	99	291.2	242.1	188	144.7	139.2	70	250.8	226.2
1 p. m.	7.8	167	223.7	211.4	149	438.2	364.3	246	189.4	182.1	106	349.8	315.5
3 p. m.	8.1	172	230.4	217.7	149	438.2	364.3	280	215.6	207.3	120	396.0	357.1
5 p. m.	6.5	106	142.0	134.2	74	217.7	180.9	145	111.6	107.3	65	214.5	193.5
7 p. m.	4.7	39	52.2	48.4	35	102.9	85.6	106	81.6	78.5	27	89.1	80.4
July 22:													
7 a. m.	1.7	6	8.0	7.6	4	11.8	9.8	15	11.5	11.1	5	16.5	14.9
9 a. m.	4.9	73	97.8	92.4	71	208.8	173.6	135	103.9	99.9	61	201.3	181.5
11 a. m.	5.7	126	168.8	159.5	71	208.8	173.6	174	133.9	128.8	65	214.5	193.5
1 p. m.	5.6	144	192.9	182.3	131	385.3	320.3	245	188.5	181.3	92	303.6	273.8
3 p. m.	5.9	170	227.7	215.2	135	397.0	330.1	237	182.4	175.4	97	320.1	288.7
5 p. m.	5.7	154	206.3	194.9	120	352.9	293.4	255	196.3	188.7	91	300.3	270.8
7 p. m.	4.6	60	80.4	76.0	46	135.3	112.7	135	103.9	99.9	30	99.0	89.3

TABLE III.—*Rate of hourly transpiration of corn and the sorghums at Garden City, Kans., in 1917*—Continued

Period ending—	Evaporation per hour.	MILO, DWARF (2).			SORGO, FREED'S (2).			FETERITA (1).			CORN, SHERROD'S WHITE DENT (1).		
		Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.
July 23:	*C. c.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
9 a. m.	4.7	101	159.6	147.5	66	223.7	198.2	82	226.5	203.5	209	191.6	177.7
11 a. m.	6.1	145	229.1	211.8	106	359.3	318.3	103	284.5	255.6	298	273.1	253.4
1 p. m.	6.5	177	279.6	258.6	120	406.8	360.4	149	411.6	369.7	344	315.3	292.5
3 p. m.	7.3	183	289.1	267.3	119	403.4	357.4	135	372.9	335.0	312	286.0	265.3
5 p. m.	6.7	140	221.2	204.5	97	328.8	291.3	85	234.8	210.9	259	237.4	220.2
7 p. m.	5.1	46	72.7	67.2	37	125.4	111.1	46	127.1	114.1	103	94.4	87.6
July 24:													
7 a. m.	1.1	4	6.3	5.8	6	20.3	18.0	4	11.0	9.9	13	11.9	11.1
9 a. m.	3.5	78	123.2	114.0	58	196.6	174.2	60	165.7	148.9	195	178.7	165.8
11 a. m.	5.1	144	227.5	210.4	112	379.7	336.3	120	331.5	297.8	280	256.6	238.1
1 p. m.	6.7	181	285.9	264.4	124	420.3	372.4	152	419.9	377.2	330	302.5	280.6
3 p. m.	7.3	174	274.9	254.2	122	413.6	366.4	142	392.3	352.4	294	269.5	250.0
5 p. m.	6.3	131	207.0	191.4	85	288.1	255.3	99	273.5	245.7	234	214.5	198.8
7 p. m.	5.1	46	72.7	67.2	39	132.2	117.1	43	118.8	106.8	113	103.6	96.1
July 25:													
7 a. m.	.8	2	3.2	2.9	5	16.9	15.0	1	2.8	2.5	10	9.2	8.5
9 a. m.	2.3	60	94.8	87.7	37	125.4	111.1	53	146.4	131.5	142	130.1	120.7
11 a. m.	3.7	117	184.8	170.9	82	277.9	246.2	103	284.5	255.6	248	227.3	210.9
1 p. m.	4.4	161	254.3	235.2	99	335.6	297.3	135	372.9	335.0	280	256.6	238.1
3 p. m.	4.9	154	243.3	225.0	103	349.2	309.3	124	342.5	307.7	266	243.8	226.2
5 p. m.	4.7	119	188.0	173.9	74	250.8	222.2	82	226.5	203.5	202	185.2	171.8
7 p. m.	3.2	43	67.9	62.8	35	118.6	105.1	39	107.7	96.8	99	90.7	84.2

Period ending—	Evaporation per hour.	SORGO, RED AMBER (1).			CORN, PRIDE OF SALINE (1).			KAFIR, DWARF BLACKHULL (2).			SORGO, FREED'S (2).		
July 26:													
9 a. m.	2.9	99	204.5	180.7	206	121.6	116.1	69	102.8	96.8	53	189.6	171.8
11 a. m.	4.9	142	293.4	259.1	280	165.3	157.8	110	163.9	154.3	85	304.1	275.5
1 p. m.	5.5	181	373.9	330.3	365	215.5	205.7	117	174.4	164.1	105	375.7	340.4
3 p. m.	5.6	206	483.6	421.3	337	198.9	190.0	126	187.8	176.7	106	379.2	343.6
5 p. m.	5.3	163	382.6	333.3	273	161.2	153.9	89	132.6	124.8	76	271.9	246.4
7 p. m.	4.1	53	124.4	108.4	159	93.9	89.6	39	58.1	54.7	41	146.7	132.9
July 27:													
7 a. m.	2.1	9	21.1	18.4	24	14.2	13.5	4	6.0	5.6	7	25.0	22.7
9 a. m.	4.0	96	225.4	196.3	198	116.9	111.7	82	122.2	115.0	62	221.8	201.0
11 a. m.	4.9	163	382.6	333.3	340	200.7	191.7	122	181.8	171.1	96	343.5	311.2
1 p. m.	6.7	202	474.2	413.1	376	222.0	212.0	140	208.6	196.4	126	450.8	408.4
3 p. m.	8.1	198	464.8	404.9	337	198.9	190.0	119	177.3	166.9	115	411.5	372.8
5 p. m.	7.3	142	293.4	259.1	291	171.8	164.1	97	144.6	136.0	78	279.0	252.8
7 p. m.	6.0	57	133.8	116.6	191	112.8	107.8	44	65.6	61.7	46	164.6	149.1

Period ending—	Evaporation per hour.	SORGO, RED AMBER (1).			KAFIR, DWARF BLACKHULL (2).			FETERITA (2).			CORN, FREED'S WHITE DENT (1).		
July 30:													
9 a. m.	3.7	71	178.8	153.3	76	106.1	100.1	67	186.1	166.7	159	177.3	161.9
11 a. m.	4.5	135	340.1	291.6	129	180.2	170.0	94	261.1	233.8	255	284.3	259.7
1 p. m.	6.7	198	498.7	427.6	173	241.6	227.9	142	394.4	353.2	305	340.0	310.6
3 p. m.	7.6	220	554.2	475.2	175	244.4	230.6	149	413.9	370.6	[a] 418	275.0	258.0
5 p. m.	6.8	138	347.6	298.1	128	178.8	168.7	87	241.7	216.4	315	207.2	194.4
7 p. m.	6.1	89	224.2	192.2	50	69.8	65.9	50	138.9	124.4	195	128.3	120.4
July 31:													
7 a. m.	2.7	13	32.7	28.1	7	9.8	9.2	7	19.4	17.4	31	20.4	19.1
9 a. m.	3.7	64	161.2	138.2	66	92.2	87.0	46	127.8	114.4	213	140.1	131.5
11 a. m.	5.2	128	322.4	276.4	160	223.5	210.8	103	286.1	256.2	308	202.6	190.1
1 p. m.	5.5	135	340.1	291.6	149	208.1	196.3	112	311.1	278.6	301	198.0	185.8
3 p. m.	9.0	163	410.6	352.1	161	224.9	212.2	115	319.4	286.0	354	232.9	218.5
5 p. m.	3.9	60	151.1	134.5	34	47.5	44.8	27	75.0	67.2	92	60.5	56.8
7 p. m.	2.7	28	70.5	60.5	12	16.8	15.8	12	33.3	29.9	67	44.1	41.4

[a] New plant substituted.

TABLE III.—*Rate of hourly transpiration of corn and the sorghums at Garden City, Kans., in 1917*—Continued

Period ending—	Evaporation per hour.	CORN, SHERROD'S WHITE DENT (1).			FETERITA (2).			SORGO, RED AMBER (1).			CORN, FREED'S WHITE DENT (1).		
		Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheaf surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.	Per plant.	Per square meter of leaf surface.	Per square meter of combined leaf and sheath surface.
August 2:	*C. c.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
9 a. m.	2.2	120	110.8	101.9	34	111.8	100.9	67	162.2	140.2	142	97.5	89.3
11 a. m.	3.4	234	216.1	198.6	64	210.5	189.9	113	273.6	236.4	280	192.2	176.1
1 p. m.	4.5	259	239.2	219.9	96	315.8	284.9	156	377.7	326.4	308	211.4	193.7
3 p. m.	5.1	291	268.7	247.0	99	325.7	293.8	184	445.5	384.9	330	226.5	207.5
5 p. m.	5.1	287	265.0	243.6	73	240.1	216.6	113	273.6	236.4	294	201.8	184.9
7 p. m.	3.0	113	104.3	95.9	27	88.8	80.1	46	111.3	96.2	131	89.9	82.4
August 3:													
7 a. m.	1.1	13	12.0	11.0	3	9.9	9.0	3	7.2	6.3	14	9.6	8.8
9 a. m.	3.1	181	167.1	153.7	35	115.1	103.9	60	145.3	125.5	191	131.1	120.1
11 a. m.	4.5	252	232.7	213.9	74	243.4	219.6	145	351.1	303.3	305	209.3	191.8
1 p. m.	4.7	287	265.0	243.6	106	348.7	314.5	177	428.6	370.3	319	218.9	200.6
3 p. m.	5.9	298	275.2	253.0	106	348.7	314.5	170	411.6	355.6	337	231.3	211.9
5 p. m.	5.5	266	245.6	225.8	76	250.0	225.5	145	351.1	303.3	294	201.8	184.9
7 p. m.	4.8	142	131.1	120.5	44	144.6	130.6	60	145.3	125.5	152	104.3	95.6

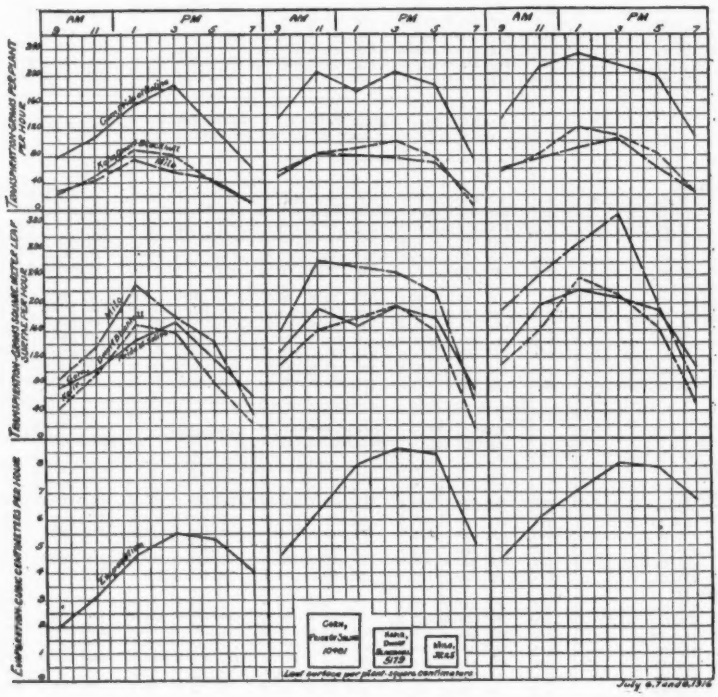


FIG. 1.—Graphs showing the amount of water transpired by Pride of Saline corn, Dwarf Blackhull kafir, and Dwarf milo during July 6, 7, and 8, 1916, and the evaporation during the corresponding period.

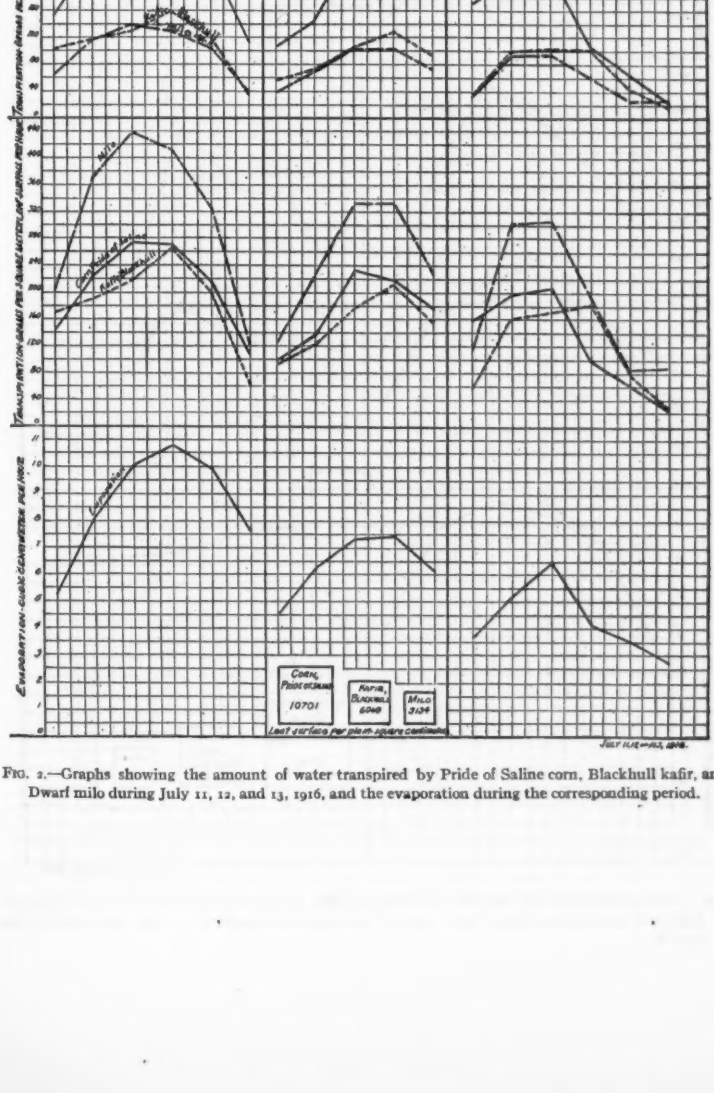


FIG. 2.—Graphs showing the amount of water transpired by Pride of Saline corn, Blackhull kafir, and Dwarf milo during July 11, 12, and 13, 1916, and the evaporation during the corresponding period.

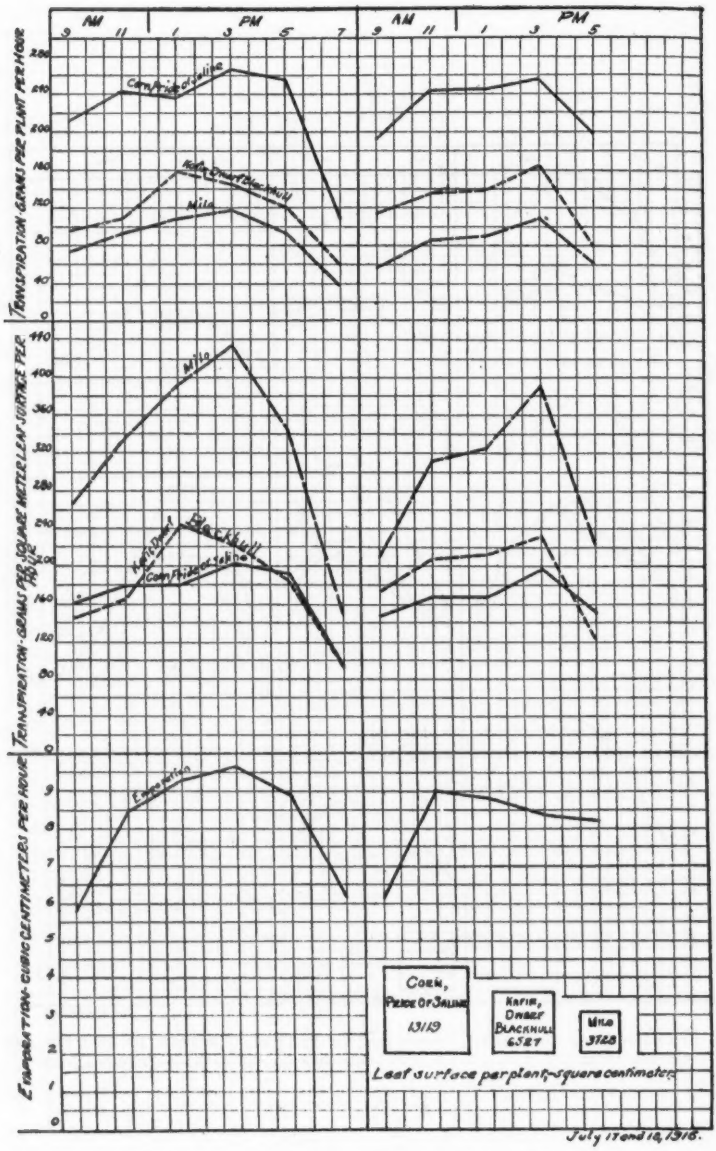


FIG. 3.—Graphs showing the amount of water transpired by Pride of Saline corn, Dwarf Blackhull kafir, and Dwarf milo during July 17 and 18, 1916, and the evaporation during the corresponding period.

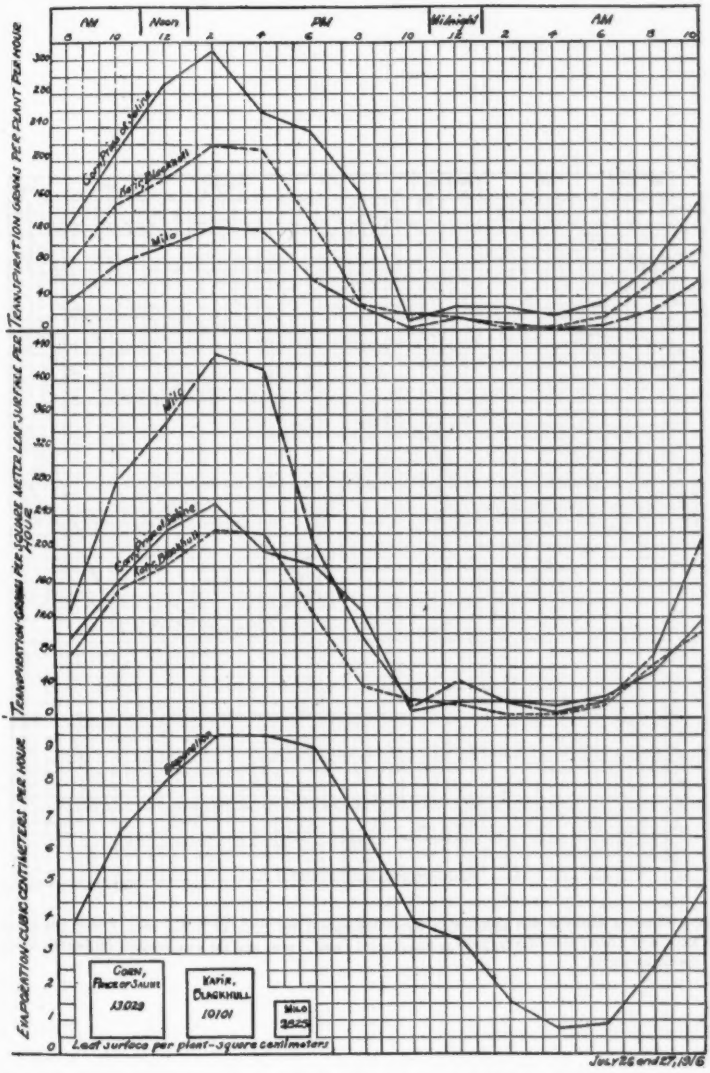


FIG. 4.—Graphs showing the amount of water transpired by Pride of Saline corn, Blackhull kafir, and Dwarf milo during July 26 and 27, 1916, and the evaporation during the corresponding period.

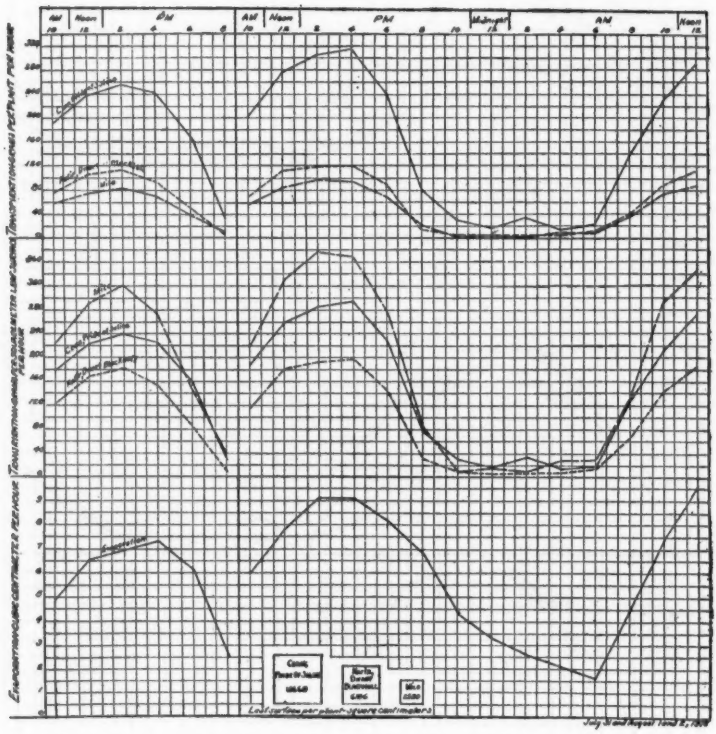


FIG. 5.—Graphs showing [the amount] of water transpired by Pride of Saline corn, Dwarf Blackhull kafir, and Dwarf milo during July 31 and August 1 and 2, 1916, and the evaporation during the corresponding period.

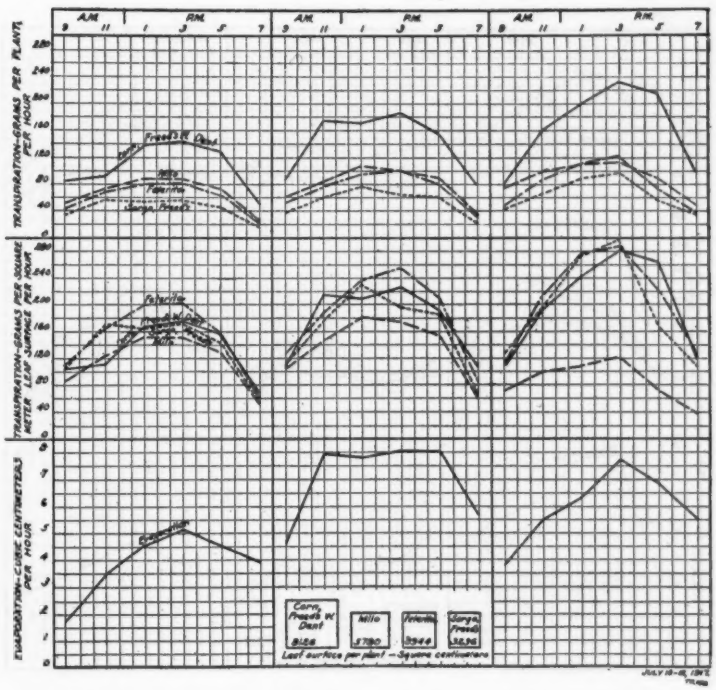


FIG. 6.—Graphs showing the amount of water transpired by Freed's White Dent corn, Dwarf milo, feterita, and Freed's sorgo during July 10, 11, and 12, 1917, and the evaporation during the corresponding period.

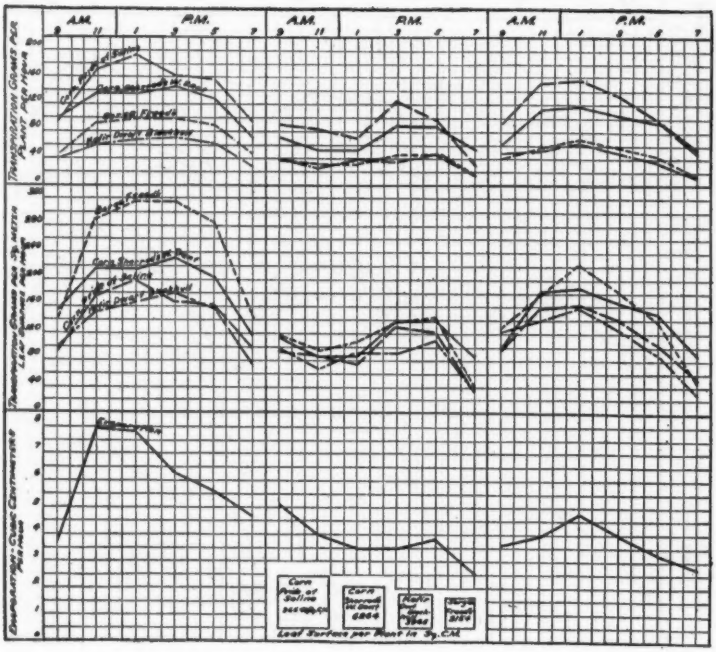


FIG. 7.—Graphs showing the amount of water transpired by Pride of Saline corn, Sherrod's White Dent corn, Dwarf Blackhull kafir, and Freed's sorgo during July 13, 14, and 15, 1917, and the evaporation during the corresponding period.

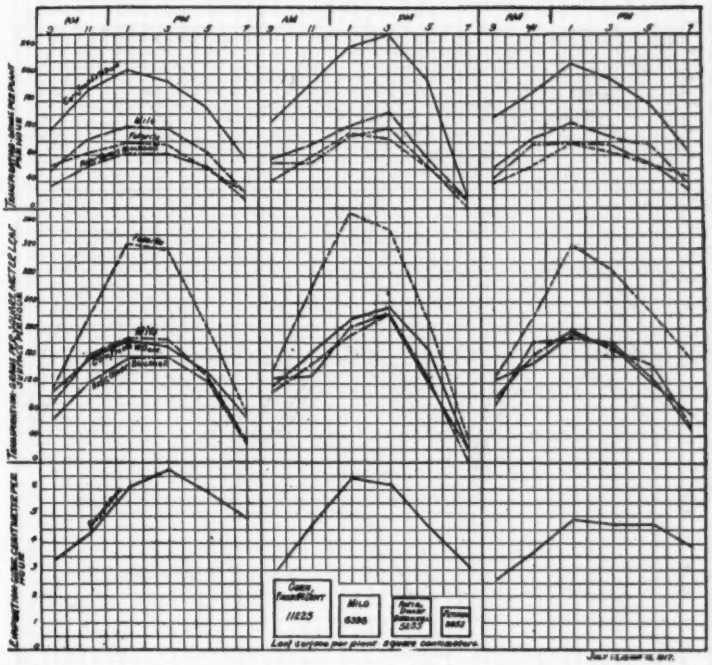


FIG. 8.—Graphs showing the amount of water transpired by Freed's White Dent corn, Dwarf milo, Dwarf Blackhull kafir, and feterita during July 17, 18, and 19, 1917, and the evaporation during the corresponding period.

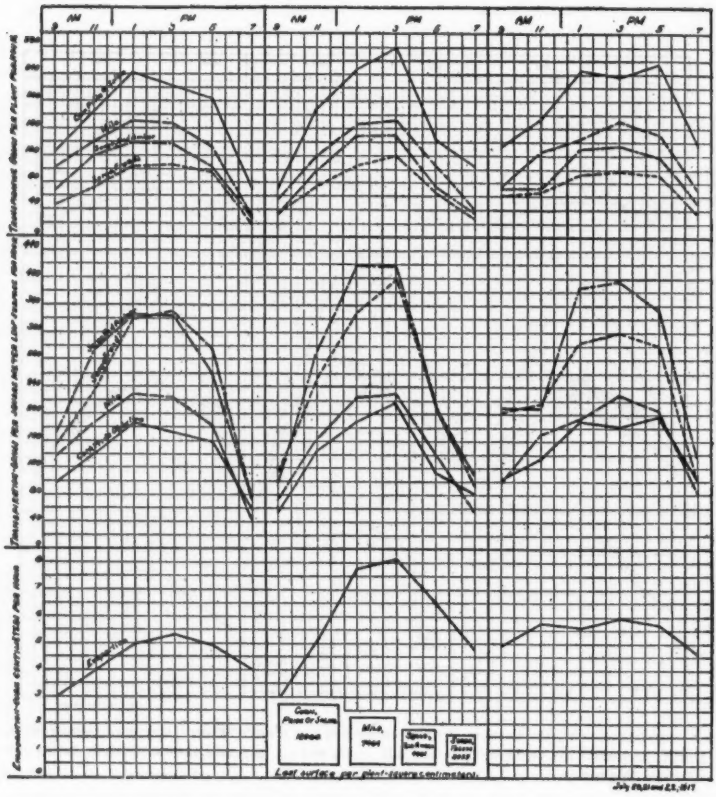


FIG. 9.—Graphs showing the amount of water transpired by Pride of Saline corn, Dwarf milo, Red Amber sorgo, and Freed's sorgo during July 20, 21, and 22, 1917, and the evaporation during the corresponding period.

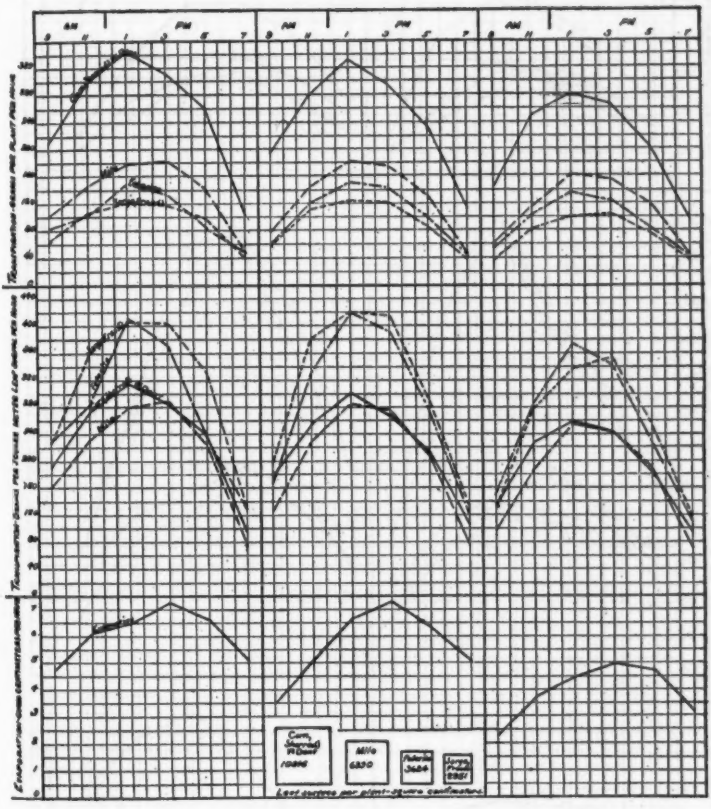


FIG. 10.—Graphs showing the amount of water transpired by Sherrod's White Dent corn, Dwarf milo, feterita, and Freed's sorgo during July 23, 24, and 25, 1917, and the evaporation during the corresponding period.

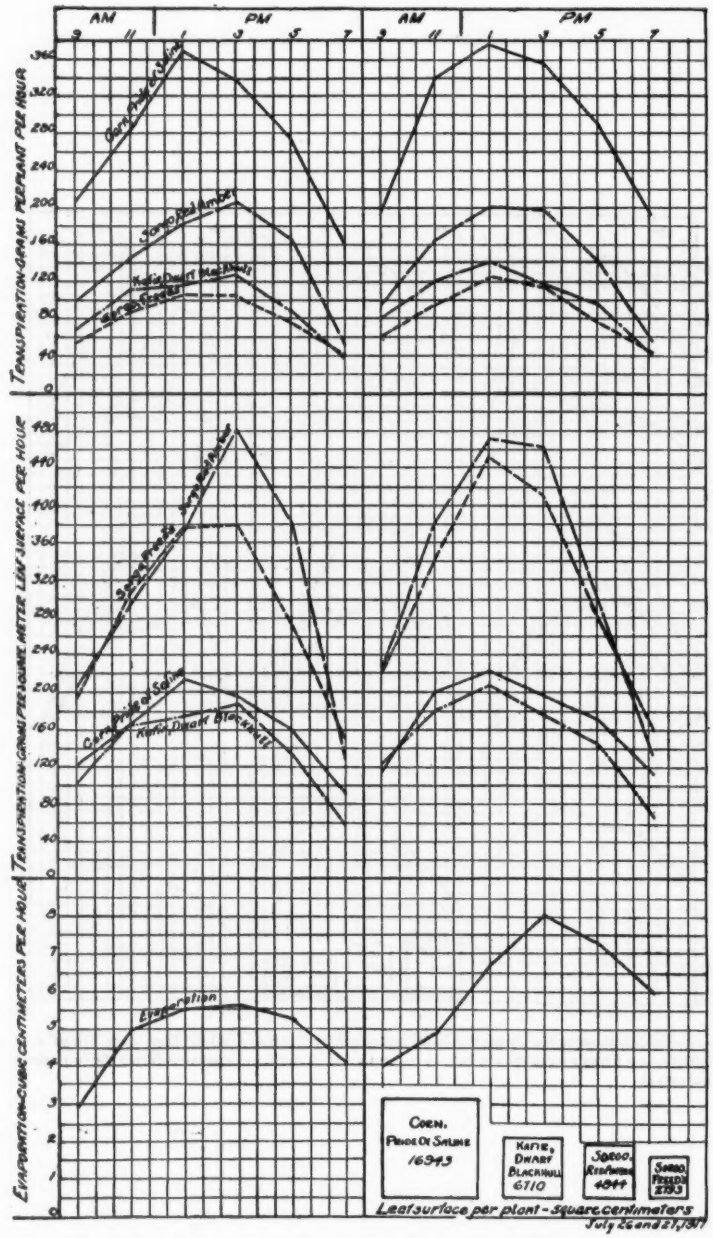

AM
PM
AM
PM
9 11 1 3 5 7 9 11 1 3 5 7
TRANSPIRATION-GRAMS PER PLANT PER HOUR
TRANSPIRATION-GRAMS PER SQUARE METER LEAF SURFACE PER HOUR
EVAPORATION-CUBIC CENTIMETERS PER HOUR
Evaporation
CORN, PRIDE OF SALINE 16943
KAFIR, DWARF BLACKHULL 6710
SORGO, RED AMBER 4944
SORGO, FREED'S 2793
Leaf surface per plant - square centimeters
July 26 and 27, 1917

FIG. 11.—Graphs showing the amount of water transpired by Pride of Saline corn, Dwarf Blackhull kafir, Red Amber sorgo, and Freed's sorgo during July 26 and 27, 1917, and the evaporation during the corresponding period.

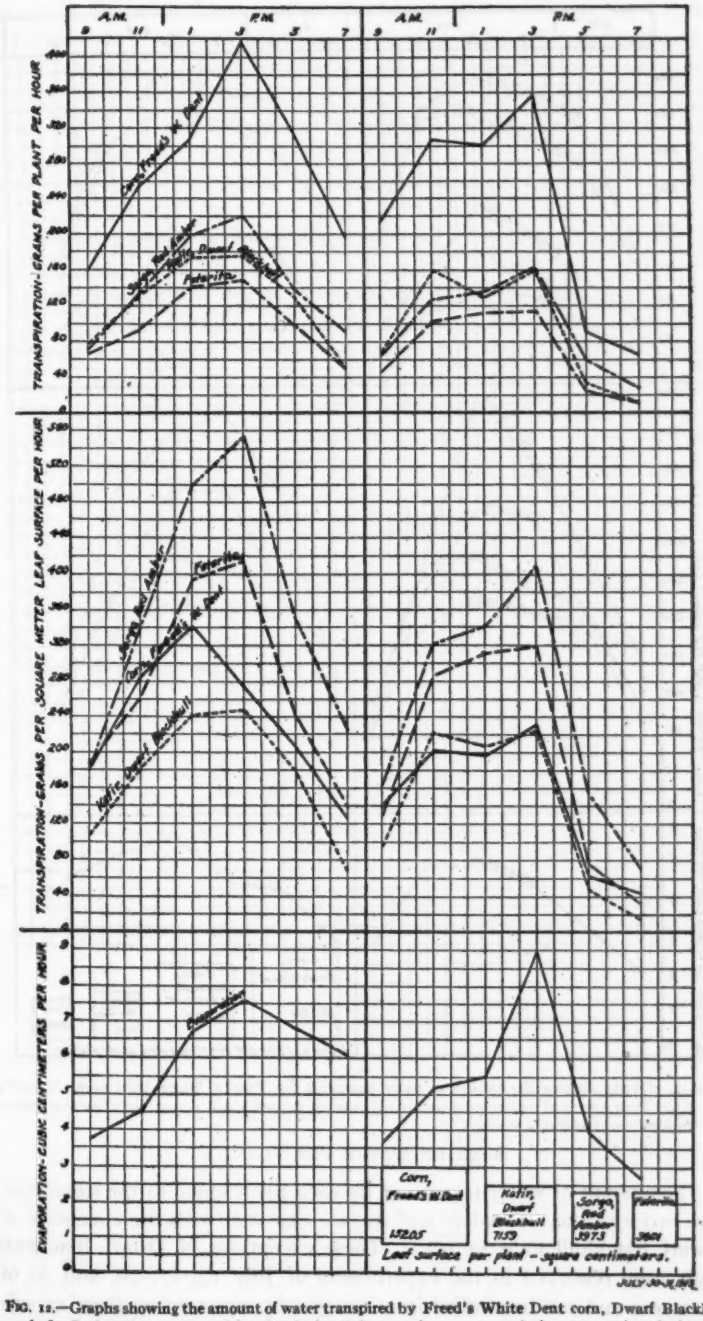


FIG. 12.—Graphs showing the amount of water transpired by Freed's White Dent corn, Dwarf Blackhull kafir, Red Amber sorgo, and feterita during July 30 and 31, 1917, and the evaporation during the corresponding period.

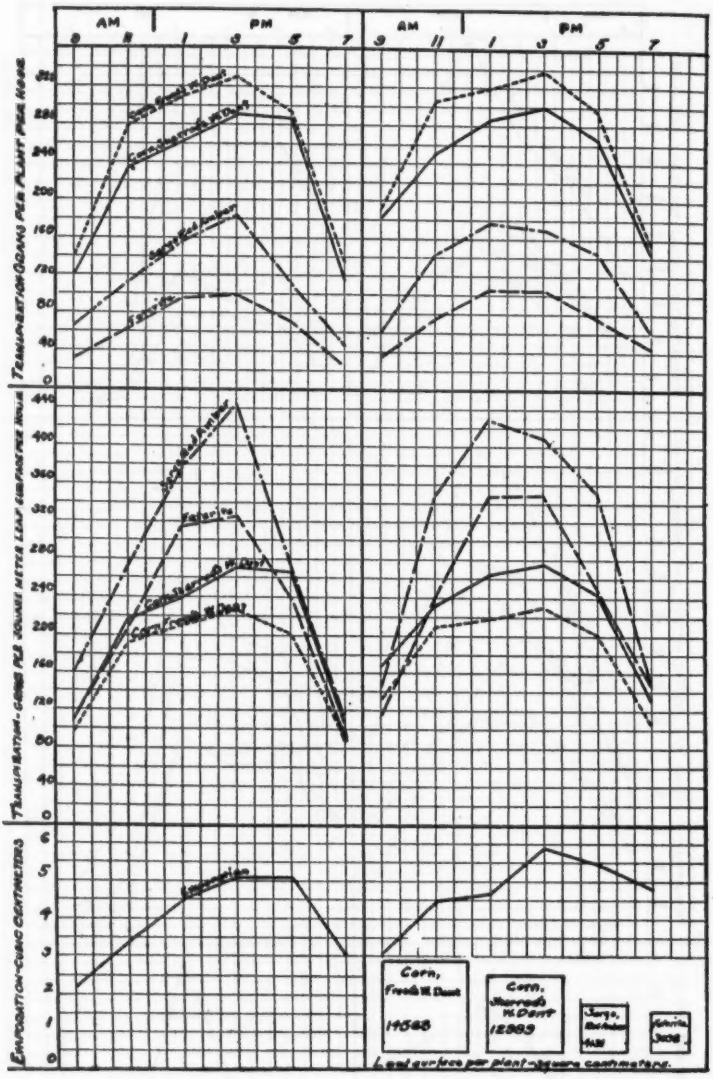


FIG. 13.—Graphs showing the amount of water transpired by Freed's White Dent corn, Sherrod's White Dent corn, Red Amber sorgo, and feterita during August 2 and 3, 1917, with the evaporation during the corresponding period.

LOSS OF WATER PER PLANT

The amount of water transpired by each plant stood in the same relative order as the amount of leaf surface exposed, with the exception of Dwarf Blackhull kafir in 1917. These exceptions of Dwarf Blackhull kafir were observed in the experiments of July 13, 17, 26, and 30 of that year and can be studied from the graphs representing these experi-

ments in figures 7, 8, 11, and 12. Only one of these exceptions will be mentioned here. The leaf surface of the plants used in the experiment of July 26 and 27, 1917, was 16,943, 6,710, 4,844 and 2,793 square centimeters, respectively, for Pride of Saline corn, Dwarf Blackhull kafir, Red Amber sorgo, and Freed's sorgo. The total amount of water transpired per plant during the two days from 7 a. m. to 7 p. m. was 3,353 gm. for Pride of Saline corn, 1,702 gm. for Red Amber sorgo, 1,154 gm. for Dwarf Blackhull kafir, and 989 gm. for Freed's sorgo.

Although in most cases the amount of water transpired by each plant stood in the same relative order as the extent of leaf surface, the loss of water from each plant was not proportional to the amount of leaf surface exposed. For examples of this fact the results of the experiments of July 20, 27, 30, and August 31, 1917, are shown in Table IV. In this table the ratio of the extent of the leaf surface of each of the sorghums to that of the corn plant is shown, together with the ratio of the water loss of each of the sorghum plants to that of corn for every 2-hour period of the day from 7 a. m. to 7 p. m. From these examples it is observed that the ratio of the water loss from the sorghum plants at any given period to that of the corn was higher than the ratio of the ex-extent of leaf surface of these two types of plants. The only exception to this was the Dwarf Blackhull kafir. The ratio of the amount of water transpired by this plant to the amount transpired by the corn plant is lower than the ratio of the extent of the leaf surface of the kafir to that of the corn.

TABLE IV.—*Relation of the amount of water transpired by corn and the sorghums to the extent of the leaf surface of these plants*

Period ending—	Ratio of—					
	Dwarf milo to Pride of Saline corn.		Red Amber sorgo to Pride of Saline corn.		Freed's sorgo to Pride of Saline corn.	
	Leaf surface.	Loss of water per plant.	Leaf surface.	Loss of water per plant.	Leaf surface.	Loss of water per plant.
1917.						
July 20:						
9 a. m.	0.578	0.814	0.310	0.540	0.234	0.370
11 a. m.	.578	.773	.310	.646	.234	.392
1 p. m.	.578	.705	.310	.572	.234	.427
3 p. m.	.578	.748	.310	.618	.234	.475
5 p. m.	.578	.655	.310	.500	.234	.461
7 p. m.	.578	.422	.310	.394	.234	.267
	Dwarf Blackhull kafir to Pride of Saline corn.		Red Amber sorgo to Pride of Saline corn.		Freed's sorgo to Pride of Saline corn.	
July 27:						
9 a. m.	0.396	0.414	0.285	0.484	0.164	0.313
11 a. m.	.396	.358	.285	.479	.164	.282
1 p. m.	.396	.372	.285	.537	.164	.335
3 p. m.	.396	.353	.285	.587	.164	.341
5 p. m.	.396	.333	.285	.487	.164	.268
7 p. m.	.396	.230	.285	.298	.164	.240

TABLE IV.—*Relation of the amount of water transpired by corn and sorghums to the extent of the leaf surface of these plants*—Continued.

Period ending—	Ratio of—					
	Dwarf Blackhull kafir to Freed's White Dent corn.		Red Amber sorgo to Freed's White Dent corn.		Feterita to Freed's White Dent corn.	
	Leaf surface.	Loss of water per plant.	Leaf surface.	Loss of wate per plant.	Leaf surface.	Loss of water per plant.
July 30: 1917.						
9 a. m.	0.471	0.477	0.261	0.446	0.236	0.421
11 a. m.	.471	.505	.261	.529	.236	.368
1 p. m.	.471	.566	.261	.649	.236	.465
3 p. m.	.471	.418	.261	.526	.236	.356
5 p. m.	.471	.406	.261	.438	.236	.276
7 p. m.	.471	.256	.261	.456	.236	.256
	Sherrod's White Dent to Freed's White Dent corn.		Red Amber sorgo to Freed's White Dent corn.		Feterita to Freed's White Dent corn.	
August 3:						
9 a. m.	0.892	0.947	0.283	0.314	0.208	0.183
11 a. m.	.892	.826	.283	.475	.208	.242
1 p. m.	.892	.899	.283	.554	.208	.332
3 p. m.	.892	.884	.283	.504	.208	.314
5 p. m.	.892	.904	.283	.493	.208	.258
7 p. m.	.892	.934	.283	.394	.208	.289

RATE OF TRANSPIRATION

Since the loss of water from the different plants during a given period is not proportional to the extent of their leaf surfaces, it follows that the rate of transpiration per unit of leaf surface is not the same for each plant. Both the Blackhull and the Dwarf Blackhull kafirs showed the lowset transpiration rate per unit of leaf surface in all the experiments in which these plants were used. The corn plant always showed the greatest loss of water per plant, but in all the experiments, with the exception of those in which kafir was used, it showed the lowest rate of water loss per unit of leaf surface. The rate of transpiration per unit of leaf surface in any given experiment was always higher for Dwarf milo Freed's sorgo, Red Amber sorgo, and feterita than for any of the three varieties of corn that were used. In many cases the rate of transpiration for these plants was twice as high as that for corn under the same conditions. The rate of transpiration of the different plants expressed in grams per square meter of leaf surface per hour can be studied from the graphs in figures 1 to 13.

The foregoing discussion shows that the rate of transpiration per unit of leaf surface was, with the exception of the two kafirs, higher for the sorghums than for corn. This difference in transpiration rate became more marked as the leaf surface of the corn plant increased over that of the sorghums. At the earlier stages of growth, when the difference between the extent of leaf surface of these plants was small, the rate of

transpiration per unit of leaf surface was practically the same as that of the sorghums. At the later stages of growth, however, when the plants had attained their full leaf development, the rate of transpiration per unit of leaf surface was often twice as high for the sorghums as for the corn plant under the same conditions. The differences between the rate of transpiration of the corn and sorghum plants is more marked when the plants are under severe climatic conditions than when they are under more favorable environments. This was noted in the differences between the transpiration rate per unit of leaf surface of these plants during the earlier and later periods of the day as compared to those periods of the day when the evaporating power of the air was high.

The results of these experiments with corn and the sorghums seem to indicate that in most cases a small leaf surface is the most important factor in reducing the loss of water from these plants. The corn, with its large extent of leaf surface as compared to the sorghums, always transpires more water per plant in a given period than the sorghums. It is not able, however, to absorb water from the soil and to transport it to so large a leaf surface in sufficient amount to satisfy the evaporating power of the air. As a result of this deficiency, the rate of transpiration per unit of leaf surface is lower than it would be if water were supplied in sufficient quantity to meet the demands of the evaporating power of the air. The sorghums, on the other hand, have, as compared to the corn, a much smaller leaf surface and always transpire less water per plant during any given period than the corn. Since the sorghums have such a small leaf surface exposed for the evaporation of water and since they have a more elaborate root system than the corn, they are able to absorb water from the soil and transport it to the leaves in sufficient amount to satisfy the evaporating power of the air. As a result of this, their rate of transpiration per unit of leaf surface is higher than that of the corn plant.

SUMMARY

Five experiments were conducted in 1916 and eight in 1917 to determine the relative transpiration of corn and the sorghums. Pride of Saline corn, Blackhull kafir, Dwarf Blackhull kafir, and Dwarf milo were used in 1916; and in 1917, in addition to these, Freed's White Dent corn, Sherrod's White Dent corn, Freed's sorgo, Red Amber sorgo, and feterita were used. The plants were grown in large galvanized-iron cans with a capacity of about 120 kilos of soil. The soil used in 1916 had a water content of 18 per cent and a wilting coefficient of 11.1, while the moisture content of the soil used in 1917 was 22 per cent and had a wilting coefficient of 15.1. The moisture content of the soil was kept as nearly constant as possible by the addition of water to the cans from three to four times each day during the time of the experiments. The number of plants grown in each can was reduced to one plant for each of the varieties of

corn, Blackhull kafir, and Red Amber sorgo, while the number of plants of Dwarf milo, feterita, Dwarf Blackhull kafir, and Freed's sorgo varied from one to three to each can.

The transpiration was determined in most of the experiments every two hours from 7 a. m. to 7 p. m. Each experiment extended through two or three days. The cans were weighed on scales of the platform type with a carrying capacity of 180 kilos and were sensitive to about 5 gm. In 1916 the cans were placed in the open on the surface of the ground, but in 1917 they were placed in a pit in the center of a plot that was planted to corn. The pit was of such depth that the tops of the cans were on a level with the surface of the ground.

The amount of water transpired per plant in a given period stood, with the exception of Dwarf Blackhull kafir in 1917, in the same relative order as the extent of leaf surface. The amount of water transpired per plant, however, was not proportional to the extent of leaf surface. Blackhull kafir and Dwarf Blackhull kafir always had the lowest rate of transpiration per unit of leaf surface in the experiments in which these plants were used. All the varieties of corn used always transpired more water per plant during any given period than any of the sorghums. Their rate of transpiration per unit of leaf surface was, with the exception of the kafirs, always much lower than that of the sorghums. The rate of transpiration per unit of leaf surface for feterita, Dwarf milo, Freed's sorgo, and Red Amber sorgo was much higher than that of the corn plant under the same conditions. This difference in the transpiration rate of corn and the sorghums was more marked when the plants had reached their full leaf development and the difference in leaf surface of these plants had reached a maximum. The difference in the transpiration rate per unit of leaf surface was also more evident under severe climatic conditions than under conditions where the evaporation was low.

The results of these experiments with corn and the sorghums seem to indicate that in most cases a small leaf surface is the most important factor in reducing the loss of water from these plants. The corn plant is not capable of supplying its large extent of leaf surface with a sufficient amount of water to satisfy the evaporating power of the air, and as a result its rate of transpiration per unit of leaf surface falls below what it would be if the needed amount of water was supplied. The sorghums, on the other hand, with their small leaf surface are able to supply water in amounts sufficient to satisfy the evaporating power of the air and, as a result, their rate of transpiration per unit of leaf surface is higher than that of the corn.

XUM

PLATE 62

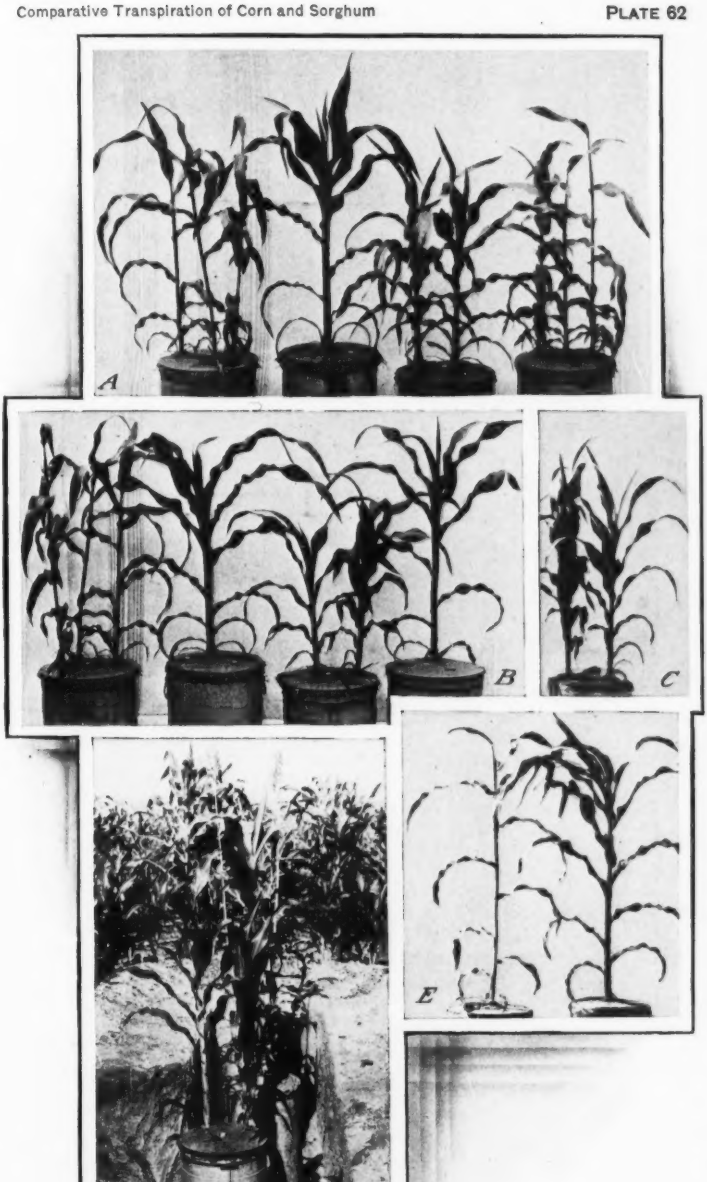
A.—Freed's sorgo, Freed's White Dent corn, Dwarf milo, and feterita. July 16, 1917.

B.—Freed's sorgo, Pride of Saline corn, Dwarf Blackhull kafir, and Sherrod's White Dent corn. July 16, 1917.

C.—Dwarf Blackhull kafir. Height of plants, 3 feet. July 30, 1917.

D.—Position of the plants in the field.

E.—Red Amber sorgo and Sherrod's White Dent corn. July 25, 1917.


A
B
C
E
19
D

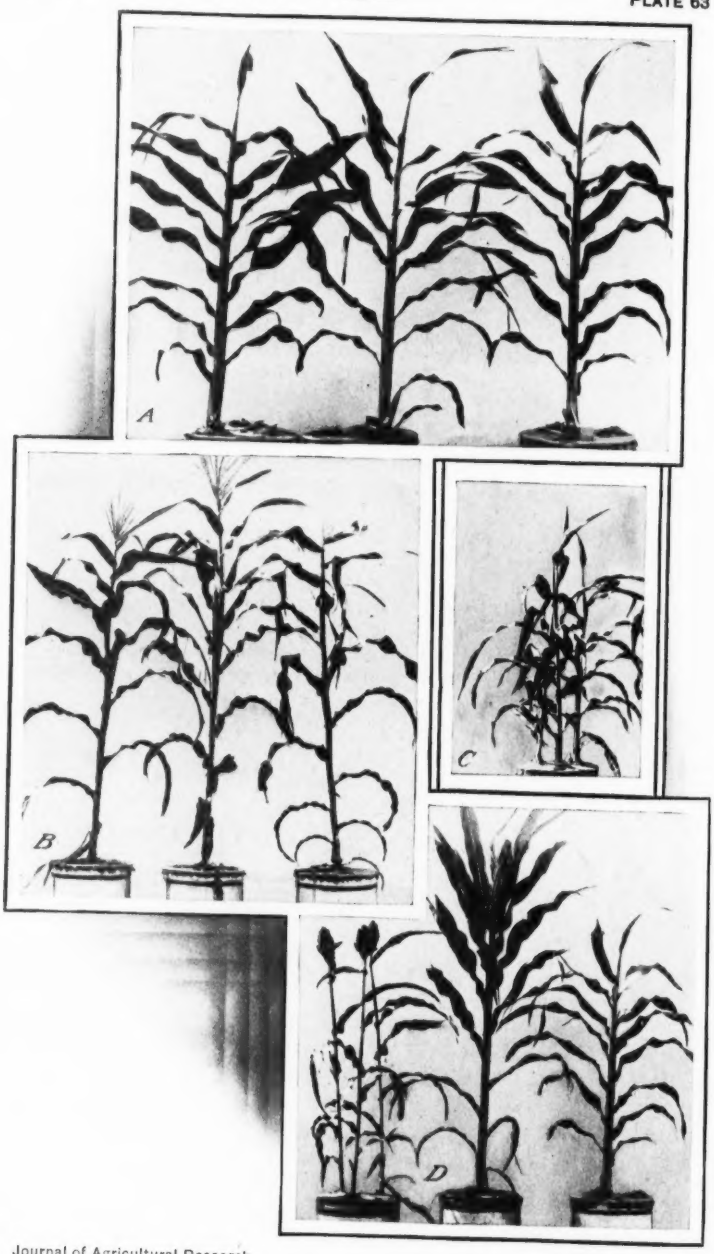

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PLATE 63

A.—Blackhull kafir, 4 feet high, heading. Used for transpiration experiments in 1916.

B.—Pride of Saline corn at period of full leaf development. Height of plants, 6 feet. Used for transpiration experiments in 1916.

C.—Dwarf milo heading. Plants 3 feet 3 inches high. July 24, 1917.

D.—Dwarf milo, Pride of Saline corn, and Dwarf Blackhull kafir. July 26, 1916.